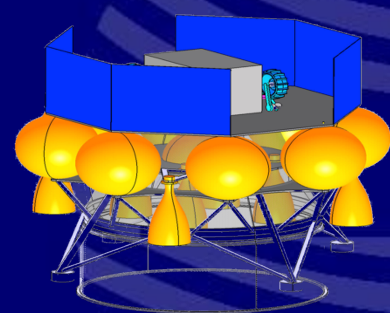
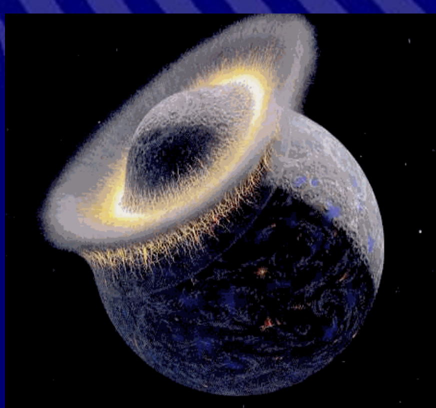
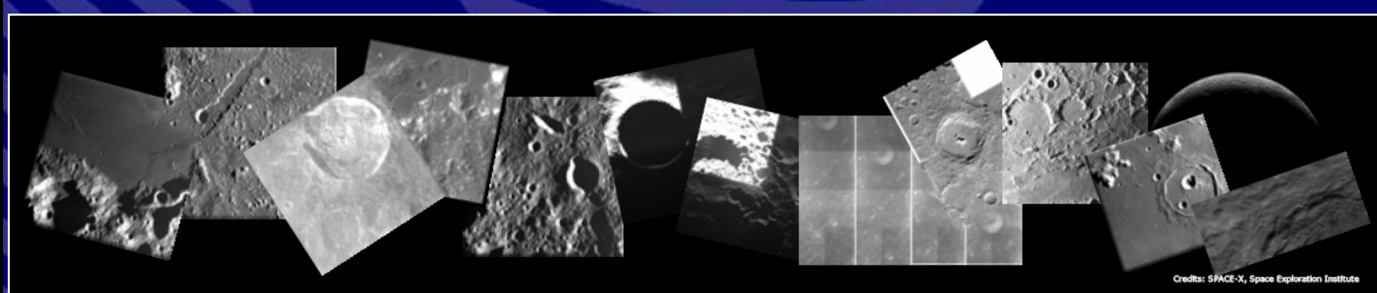
From SMART-1 to Moon Sample Return

Bernard Foing*

& SMART-1, LES3, NEXT, ILEWG Teams







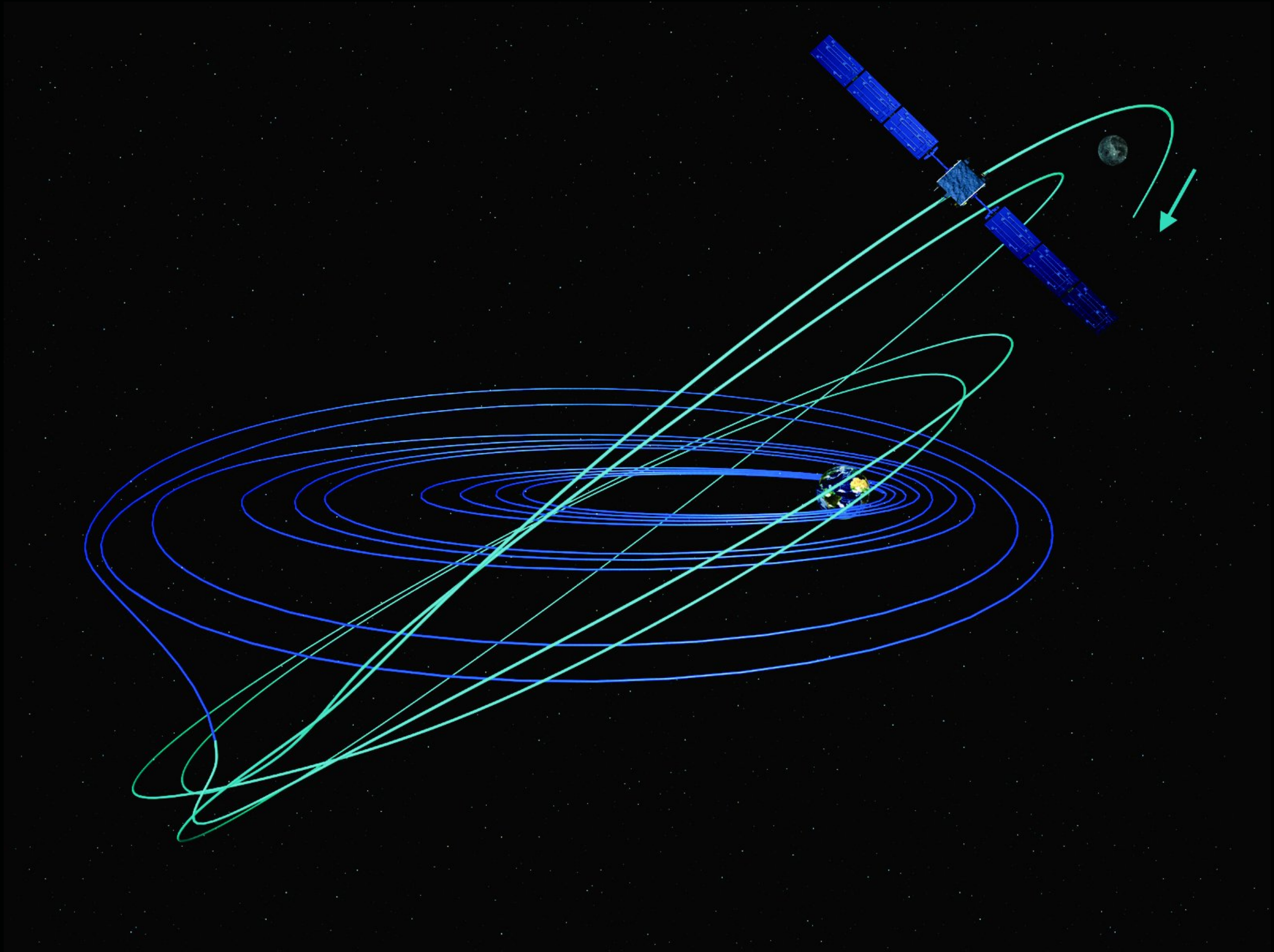
- •Senior Research Coordinator, ESA/SCI-S
- •Executive Director ILEWG

Historical Moon sample returns

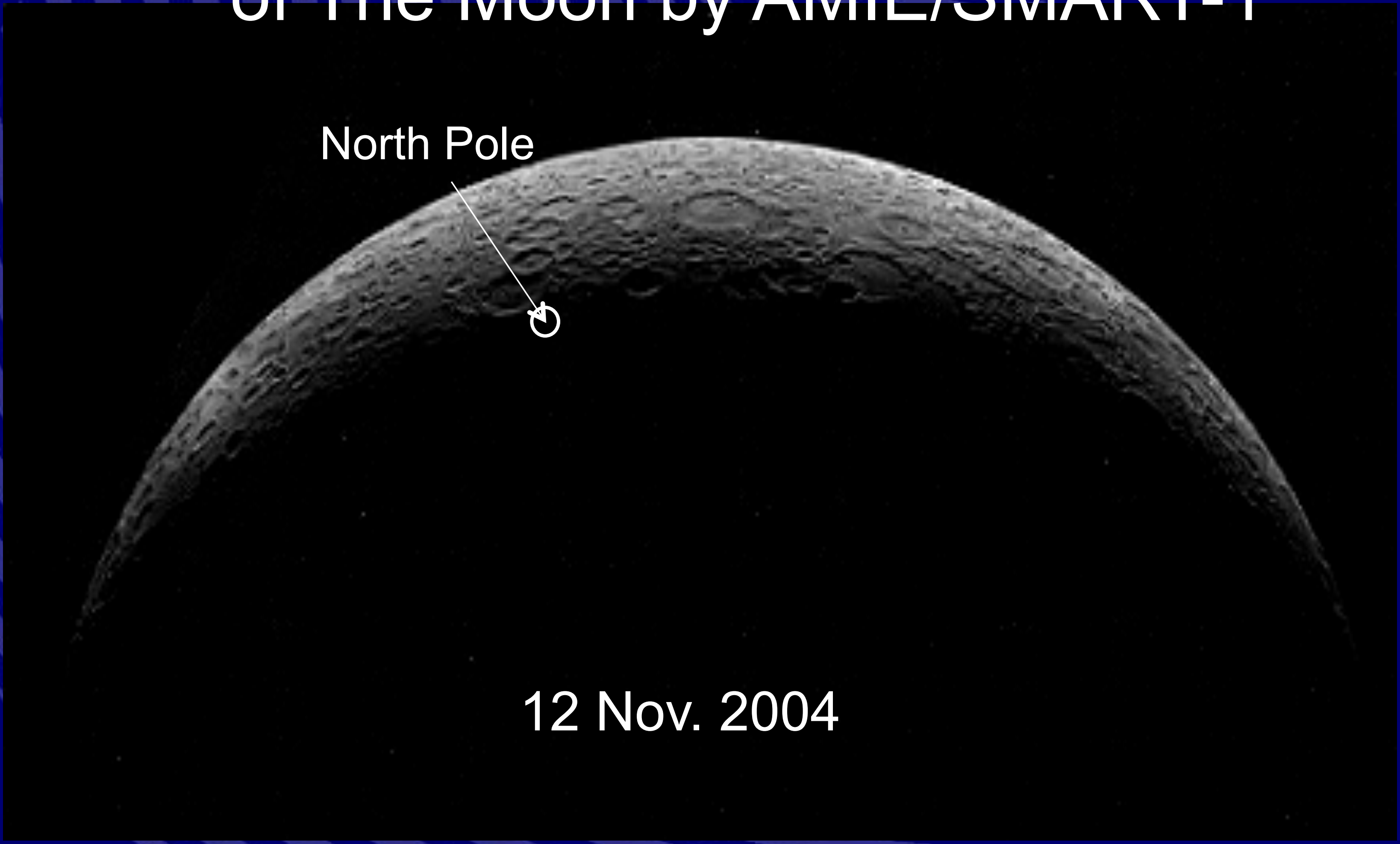
- Apollo sample return missions
- Luna 16 landed September 17, 1970
- Luna 20, launched on February 14, 1972
- Luna 24, launched on August 9, 1975.

Europe to the Moon: spacecraft, launch, operations (ESA+ industry)
Instruments PIs + TIs from 5 countries
Co-Is from 13 ESA + 6 non European countries

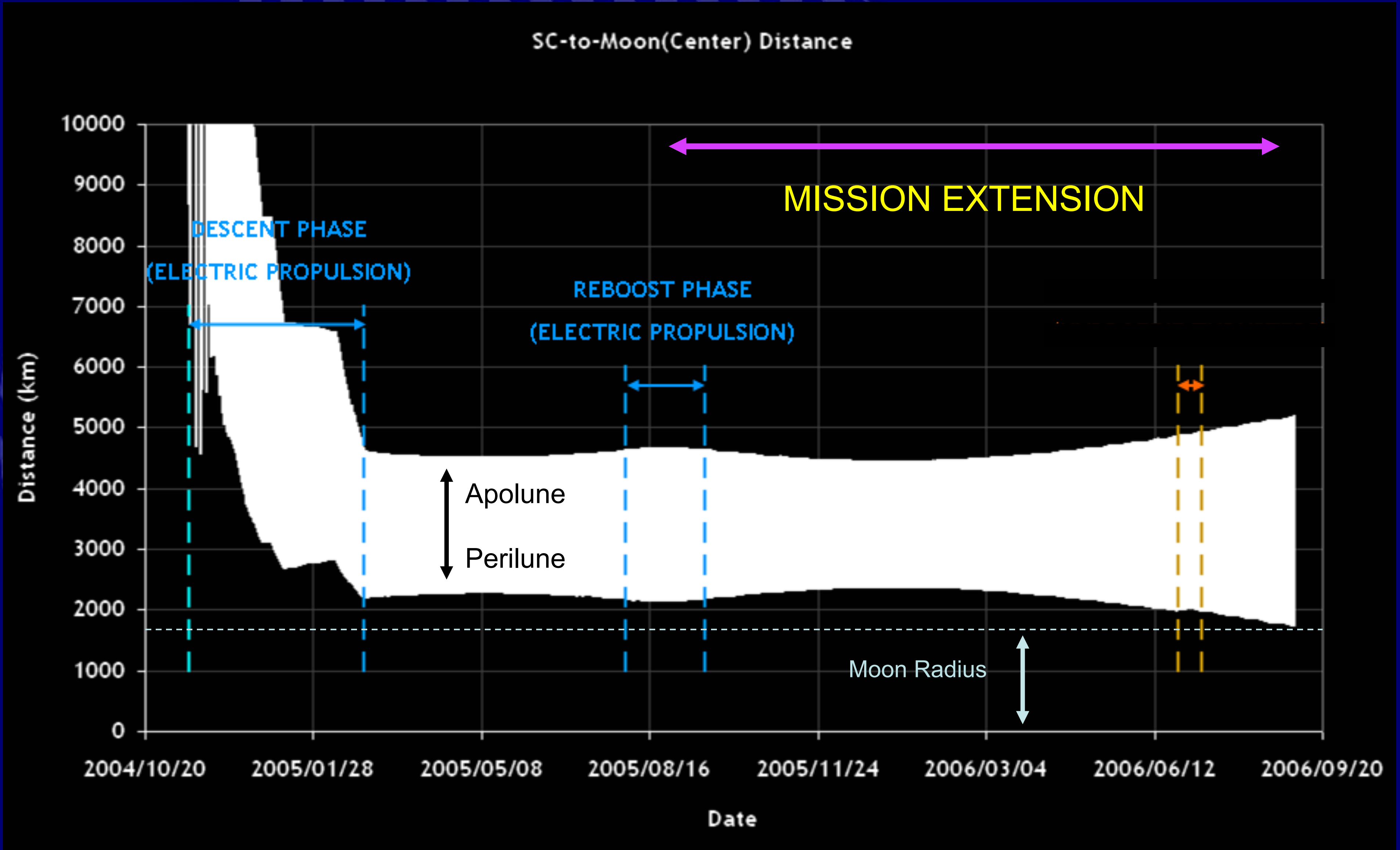
SMART-1: With Sun power to the Moon on 60 liters of fuel



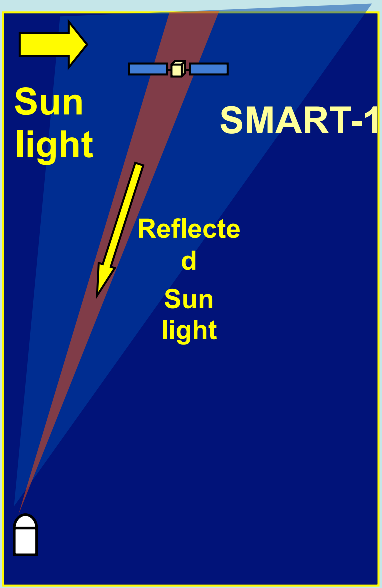
First European Far Side Image of The Moon by AMIE/SMART-1



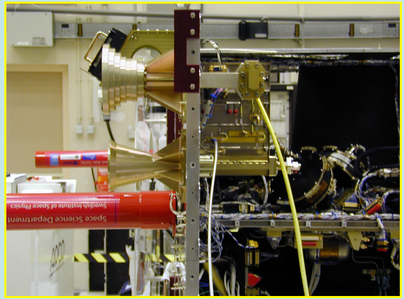
Moon Phase & Mission Extension



Why the Moon:
Innovative Technologies on Smart-1

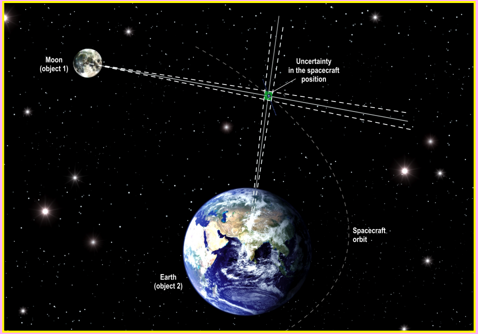


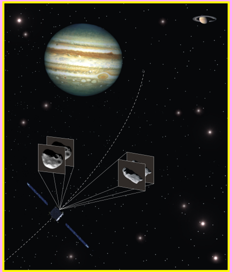
Laser Link



KA-band antenna

Communication

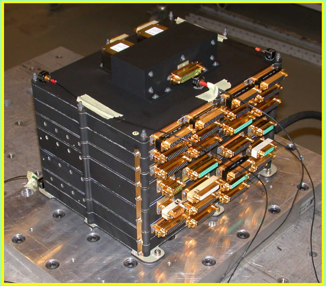




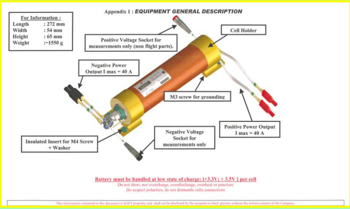
OBAN

Autonomy

Triple junction solar cells

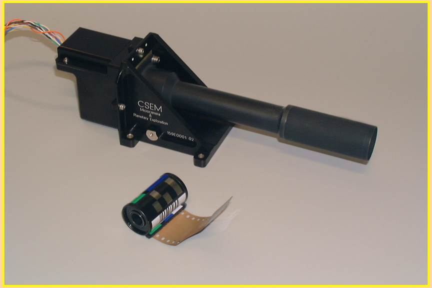


On-board computer

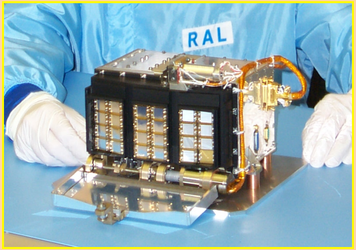


Lithium ion batteries

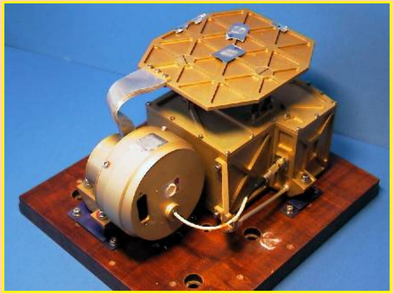
Platform Technologies



Multicolor microcamera



X-Ray Spectrometer



Infrared Spectrometer

Miniaturisation

SMART-1 last orbit

SMART-1 maps its own landing site

Lake of Excellence
46.2 W 34.4 South

Highest resolution Reference for future detection of crater and Ejectas

Impact time: 3 sept 5h42:21.7 UT (within 1 s of prediction)

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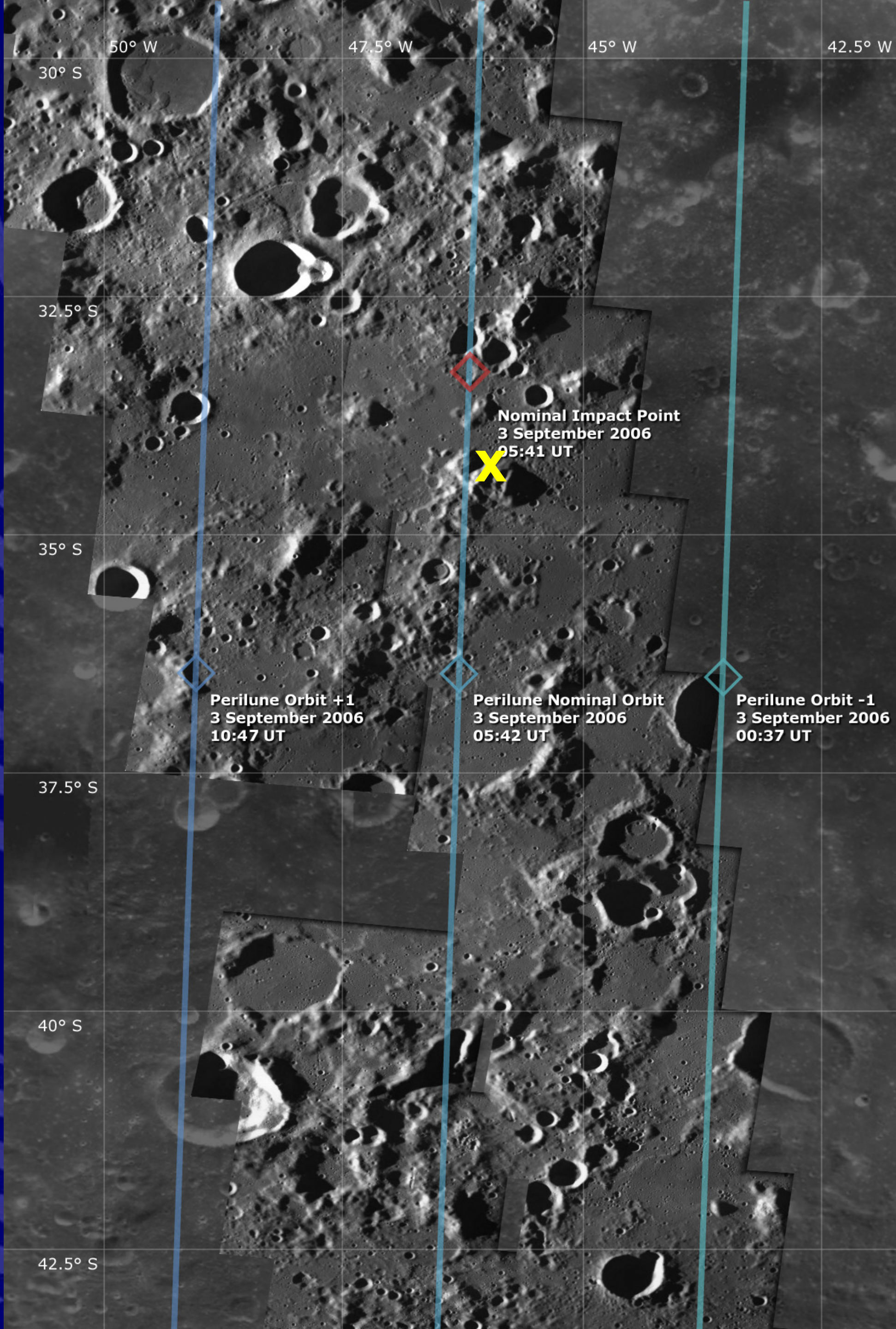
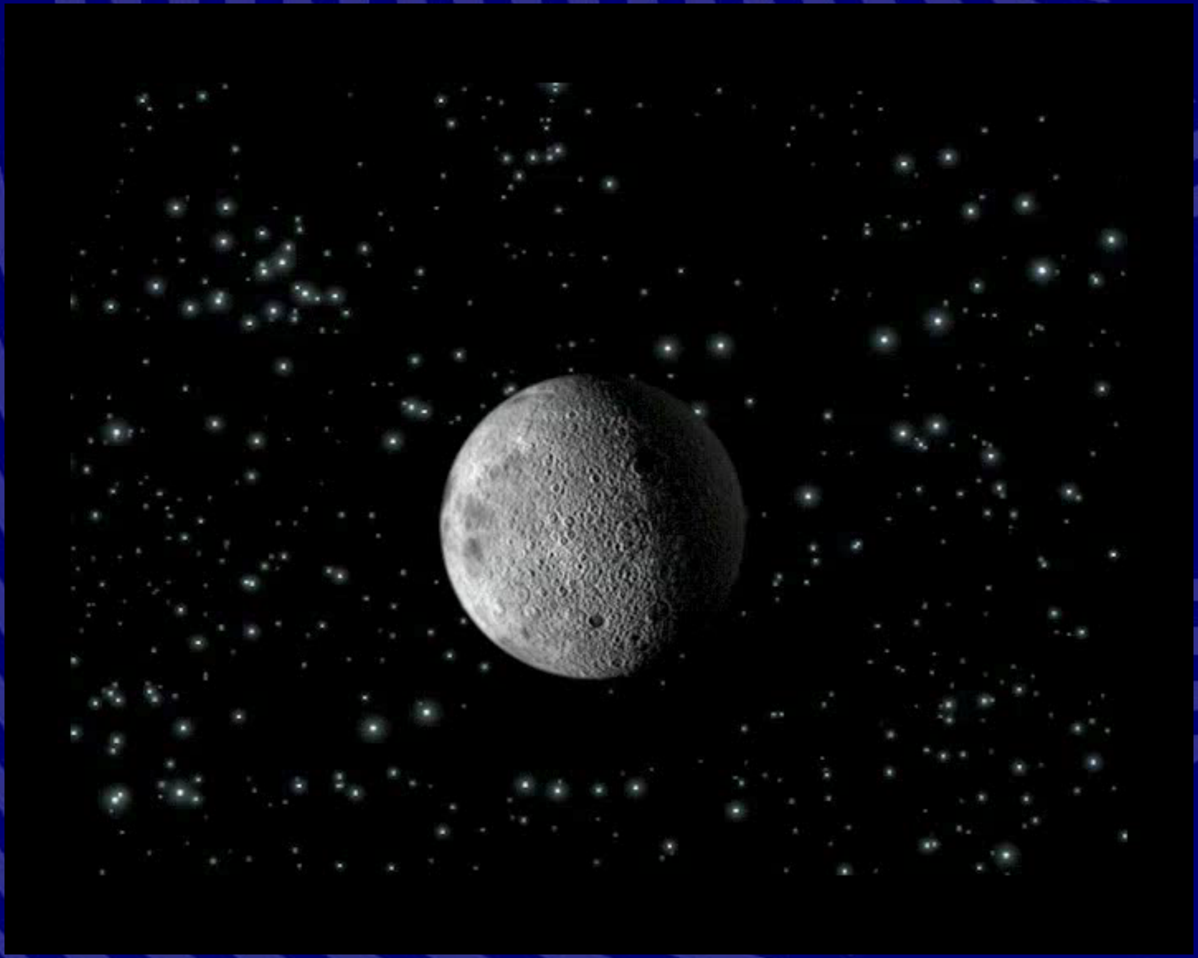


Our last Moon travelling shot



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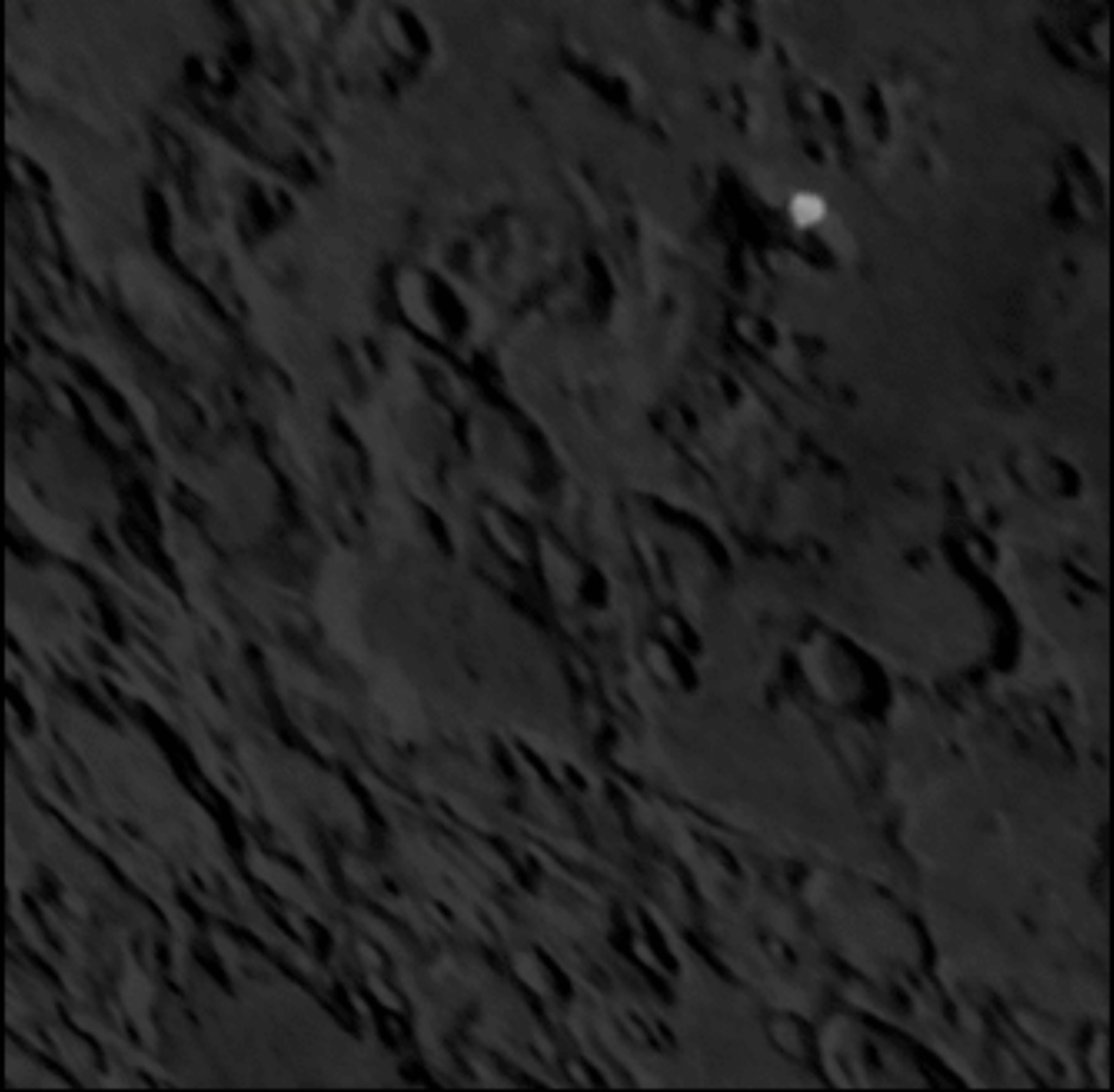
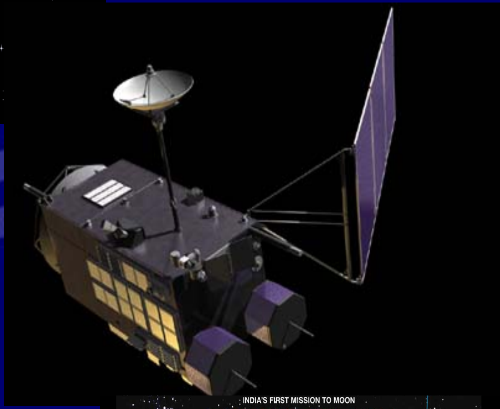


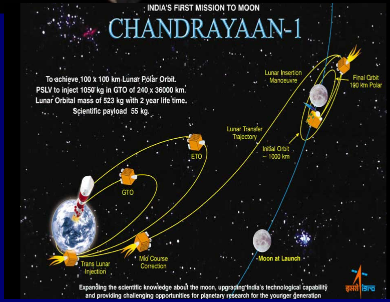
SMART-1 a bridge to Future missions

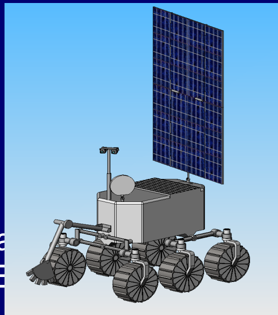


- Data analysis & Interpretation
- Technology Lessons Learned
- Science & Exploration Results
- Preparation for human lunar missions

- SMART-1 & next missions (collaborations)

2007 Chinese Chang'e 1 (ground station)
2007 JAXA Selene (science exchange)
2008 ISRO Chandrayaan-1 (SIR2, C1XS, SARA)
2008 LRO & LCROSS (reconnaissance, impact, outreach)
2011- Orbiters (ESMO, ASI, Moon Lite, BW)
2011- Landers, Rovers & Robotic village (US LPRP, Chang'e 2, Selene2, India, Lunaglob, ASI, D, UK, ESA)
2015- Sample return: Chang'e 3, Selene3, ESA NEXT,
2019- Human missions





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From SMART-1 to Lunar Sample return: Science and Exploration Themes

HOW DO EARTH-LIKE PLANETS WORK?

GEOPHYSICS: volcanism, tectonics, craters, erosion, space weather , ices

HOW DO ROCKY PLANETS FORM AND EVOLVE?

GEOCHEMISTRY: chemical composition, Earth-Moon origin, Moon evolution, accretion, collisions, giant bombardment

PREPARING FUTURE LUNAR/PLANETARY EXPLORATION

LUNAR RESOURCES SURVEY (minerals, volatiles, illumination)

HIGH RESOLUTION MAPS: for future LANDING SITES and OUTPOSTS

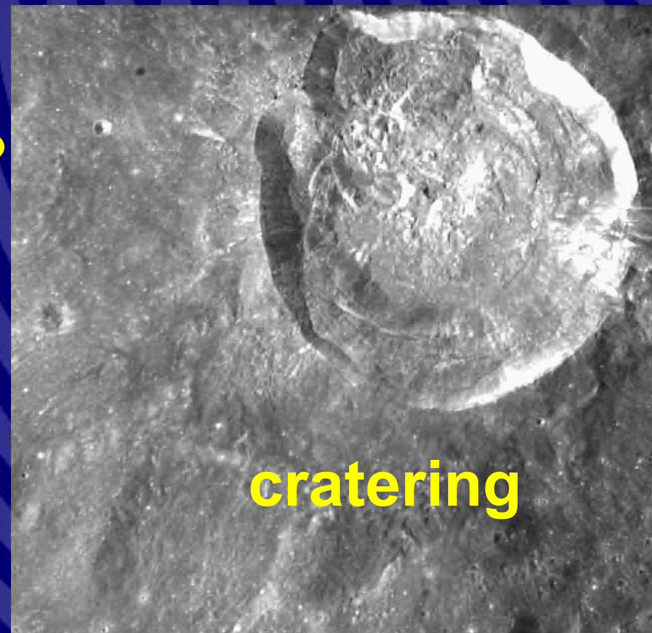
SUPPORT TO FUTURE MISSIONS AND EXPLORATION

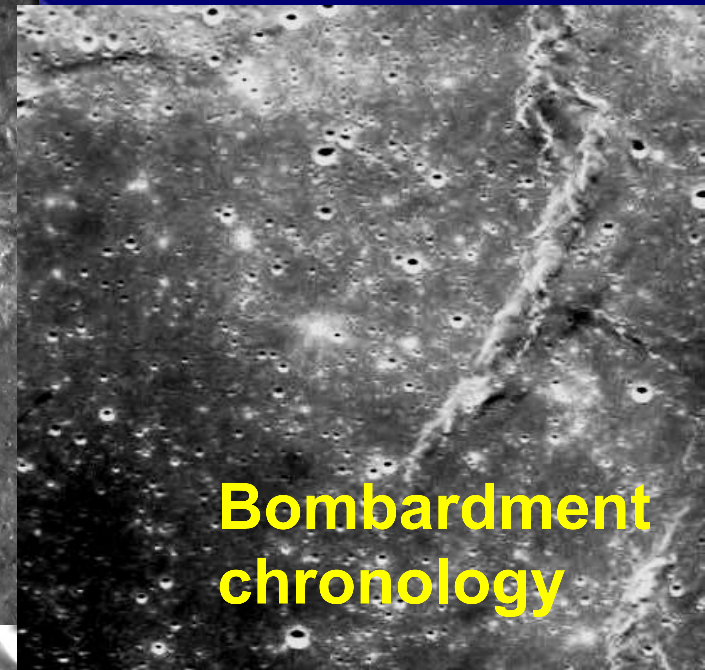
PUBLIC OUTREACH, INSPIRATION AND EDUCATION

What shapes rocky planets?

Why the Moon?
A laboratory
for Geophysics

erosion,
volatiles





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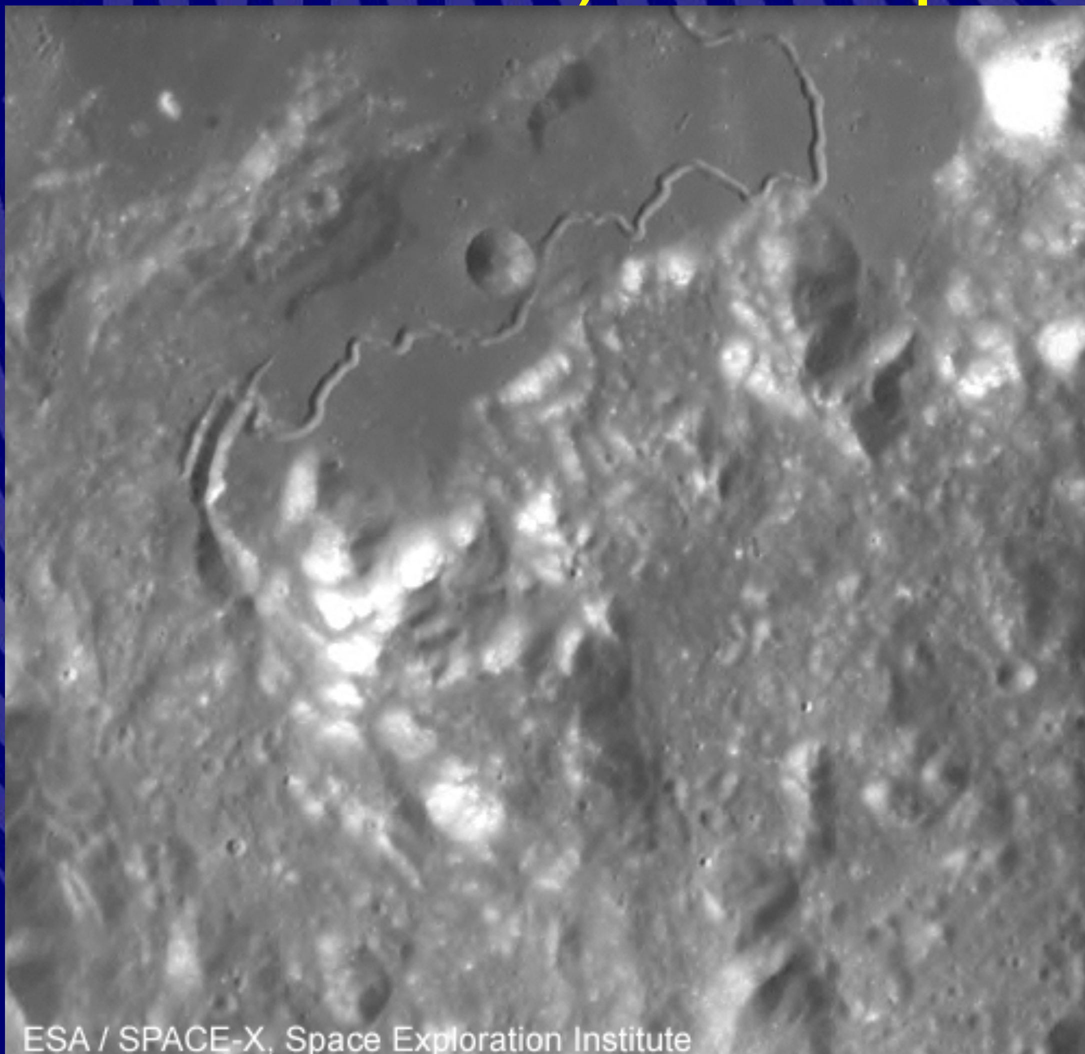
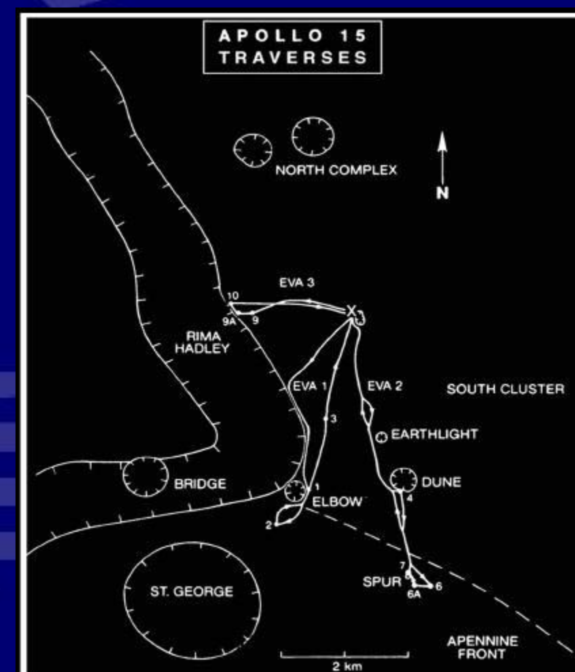
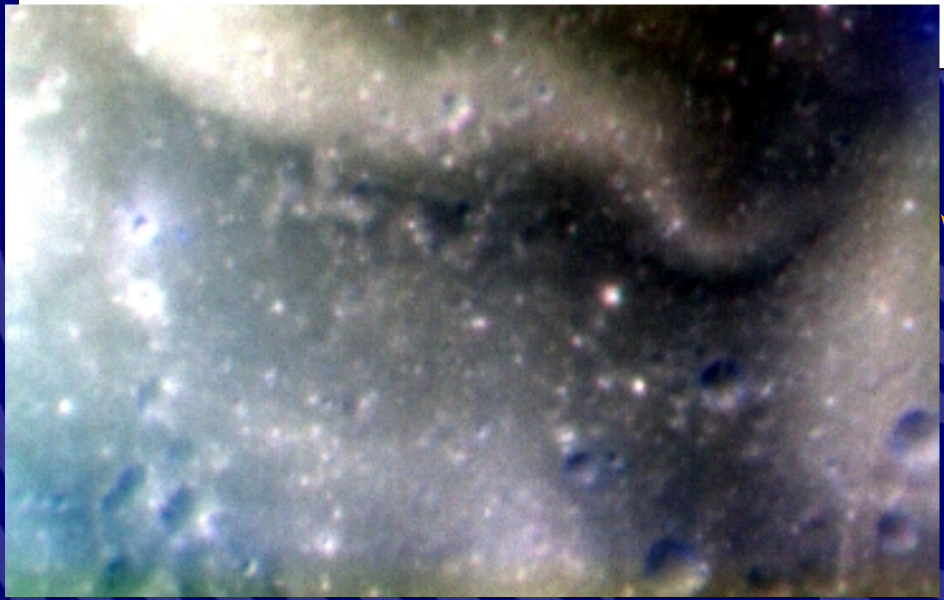
SMART-1 view of Hadley Rille (giant lava tube) near Apollo 15 landing site



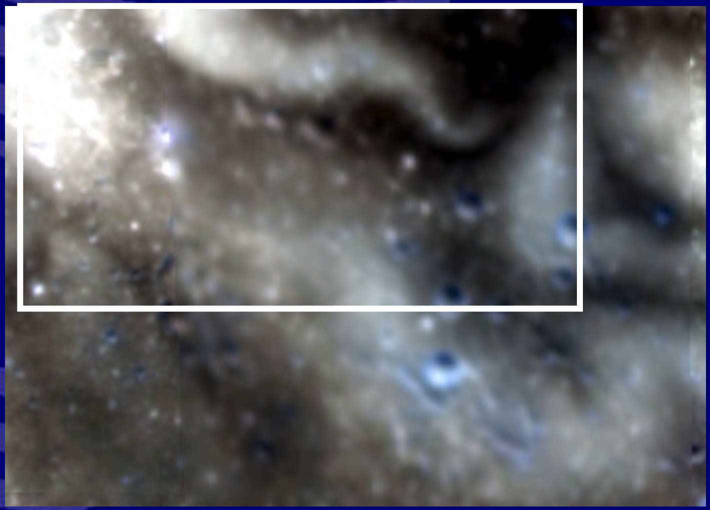


100 km field

AMIE SMART-1 High Res Colour



Clementine



AMIE colour image

Reiner gamma
Magnetic shield

Orbit 1438

Formation and evolution of rocky planets

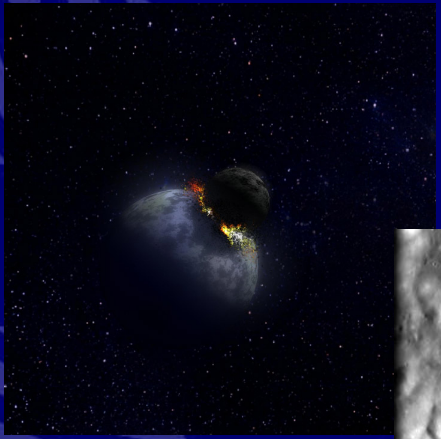
Origin of the Moon: geochemistry

Evolution of Earth/Moon system

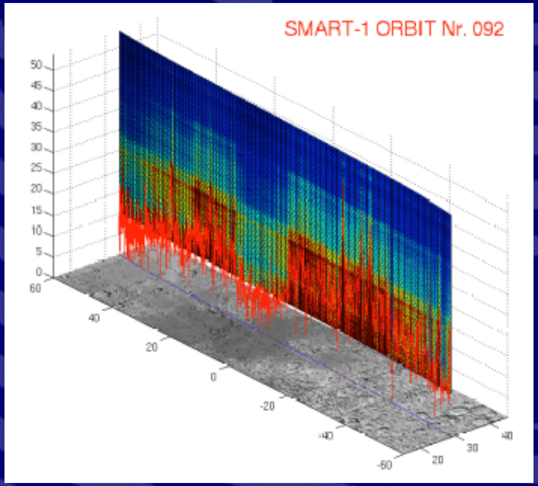
Impact craters and basins

Bombardment history in the inner solar system

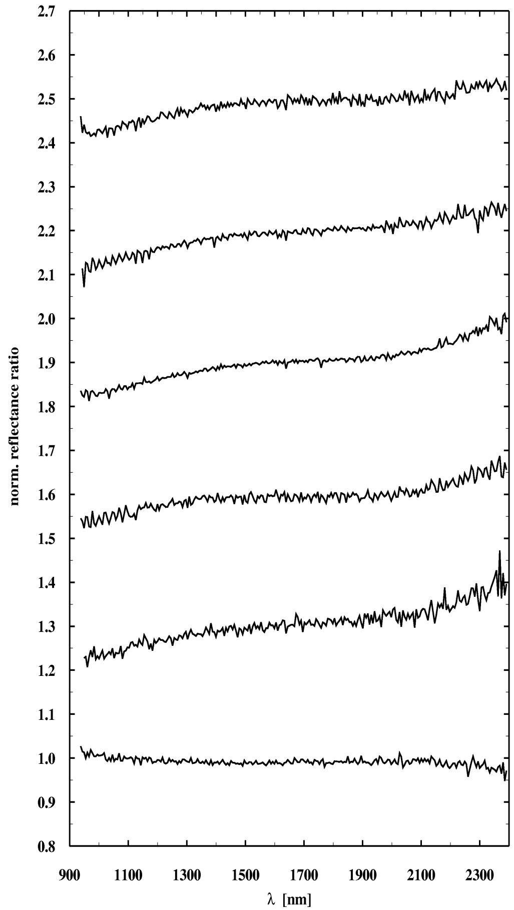
South Pole Aitken Basin



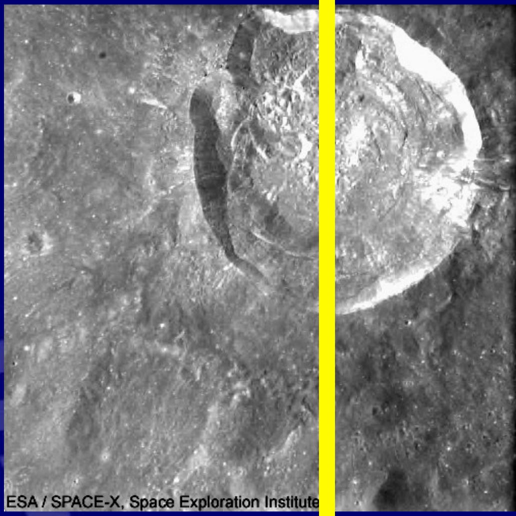
Edge debris from giant basin



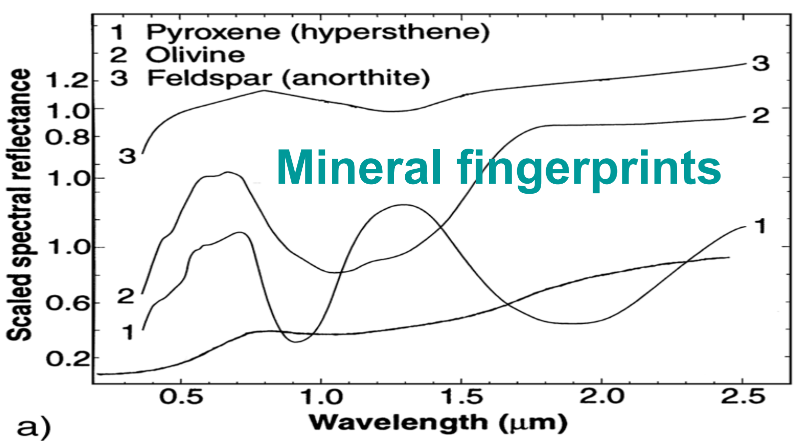
SMART-1 Infrared mineral spectroscopy

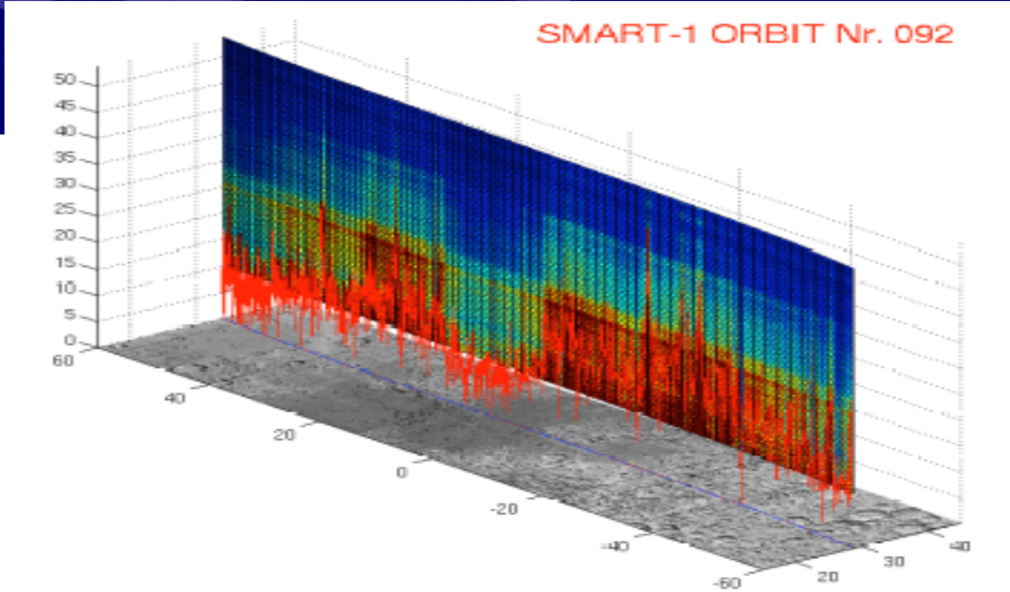


SIR infrared spectra across craters: window to the subsurface



Mineral changes with SIR: from Highland to Mare





Mapping chemical resources: How D-CIXS works

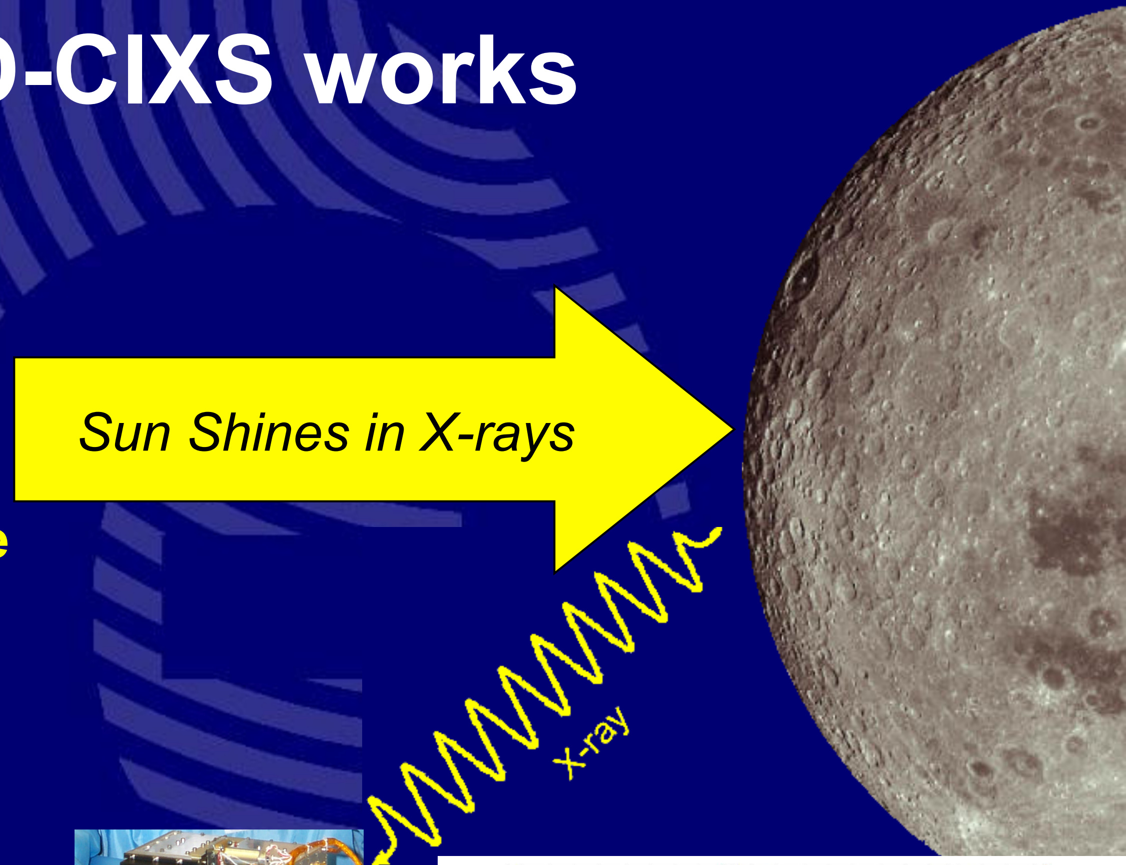
1 The Sun shines on the Moon (in X rays)

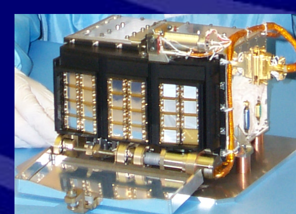
2 The Moon fluoresces

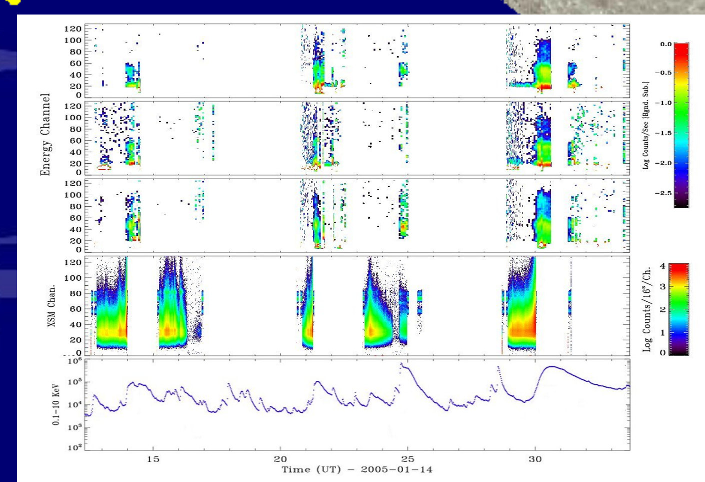
3 Each X-ray energy indicates unambiguously the abundance of a particular element

4 D-CIXS detects these X-rays

5 Solar Monitor for Solar Input required for absolute abundances







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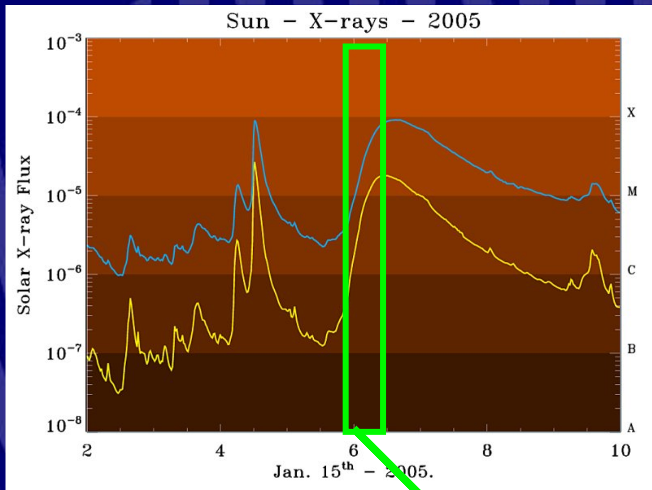
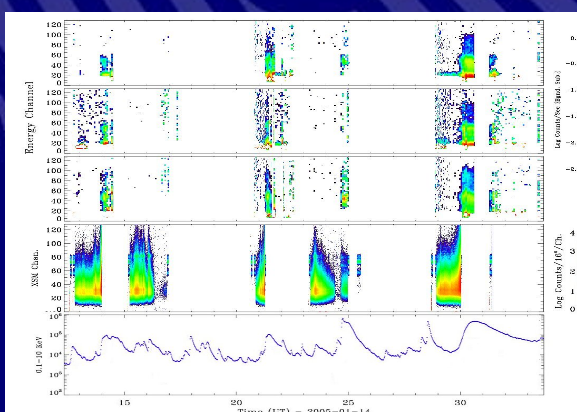
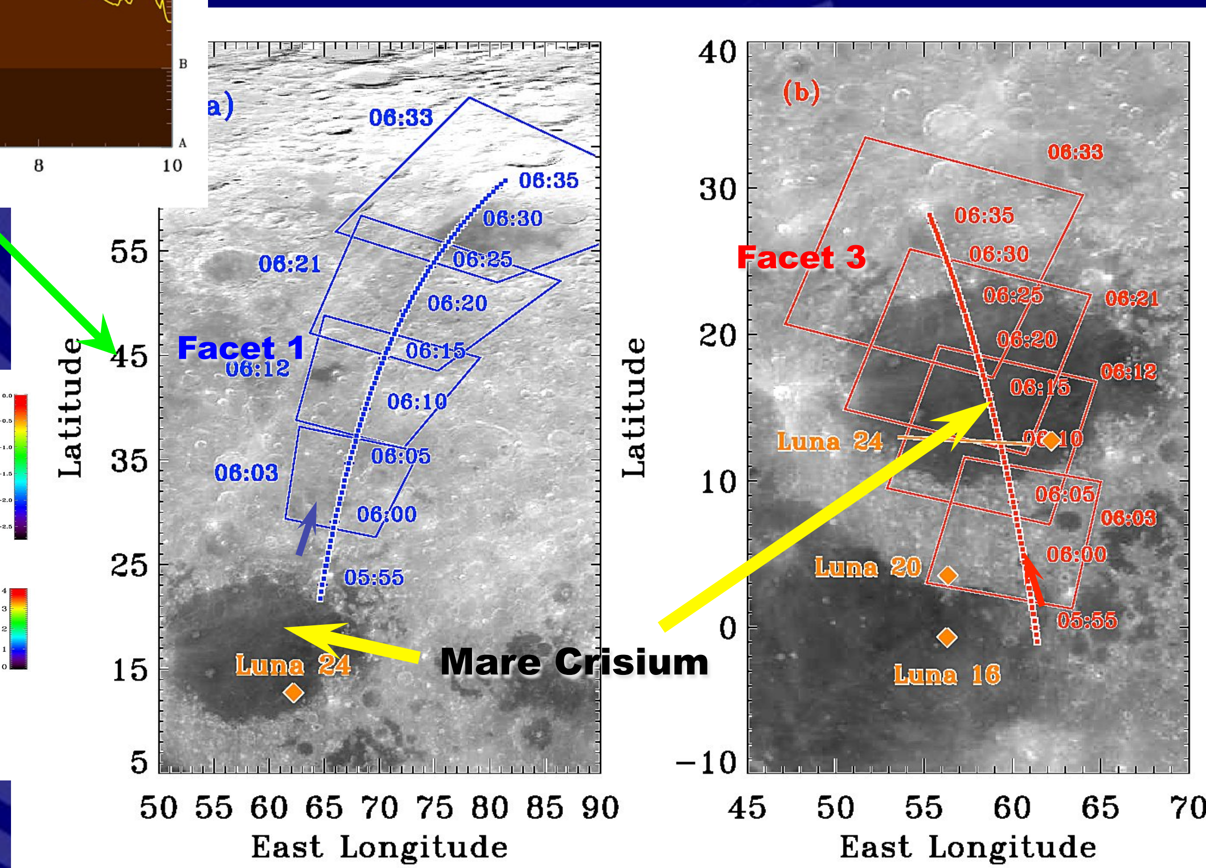
SMART-1 & Luna 24 samples in Mare Crisium : Why is Ca constant while Mg varies?

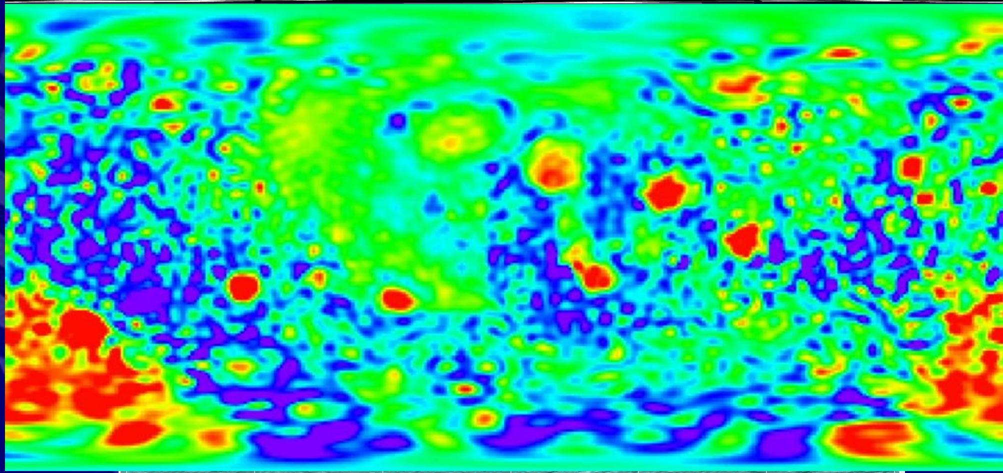






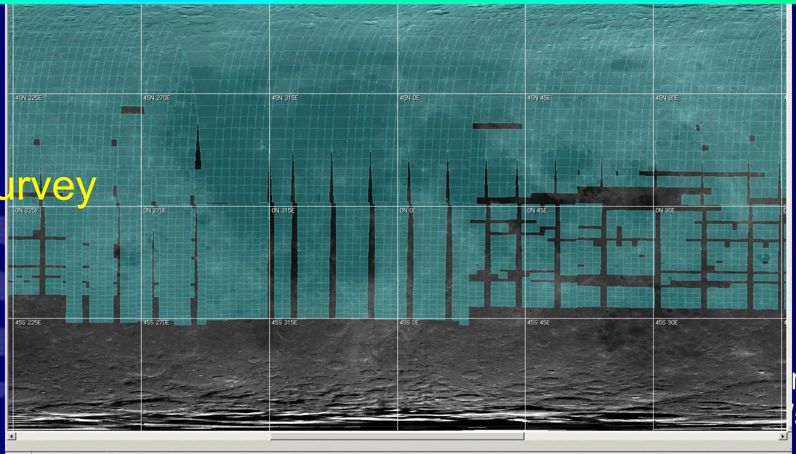
Early bombardment
Basin formation

Clementine
moon map



Gravity Bouguer
anomalies

(mascons)



SMART-1 medium res survey
1 month coverage

Impact & Magmatic evolution

- Five
- Earl … tism
- Disr
- Pos
- Pre-
- Mar … lates cau
- Ma imp

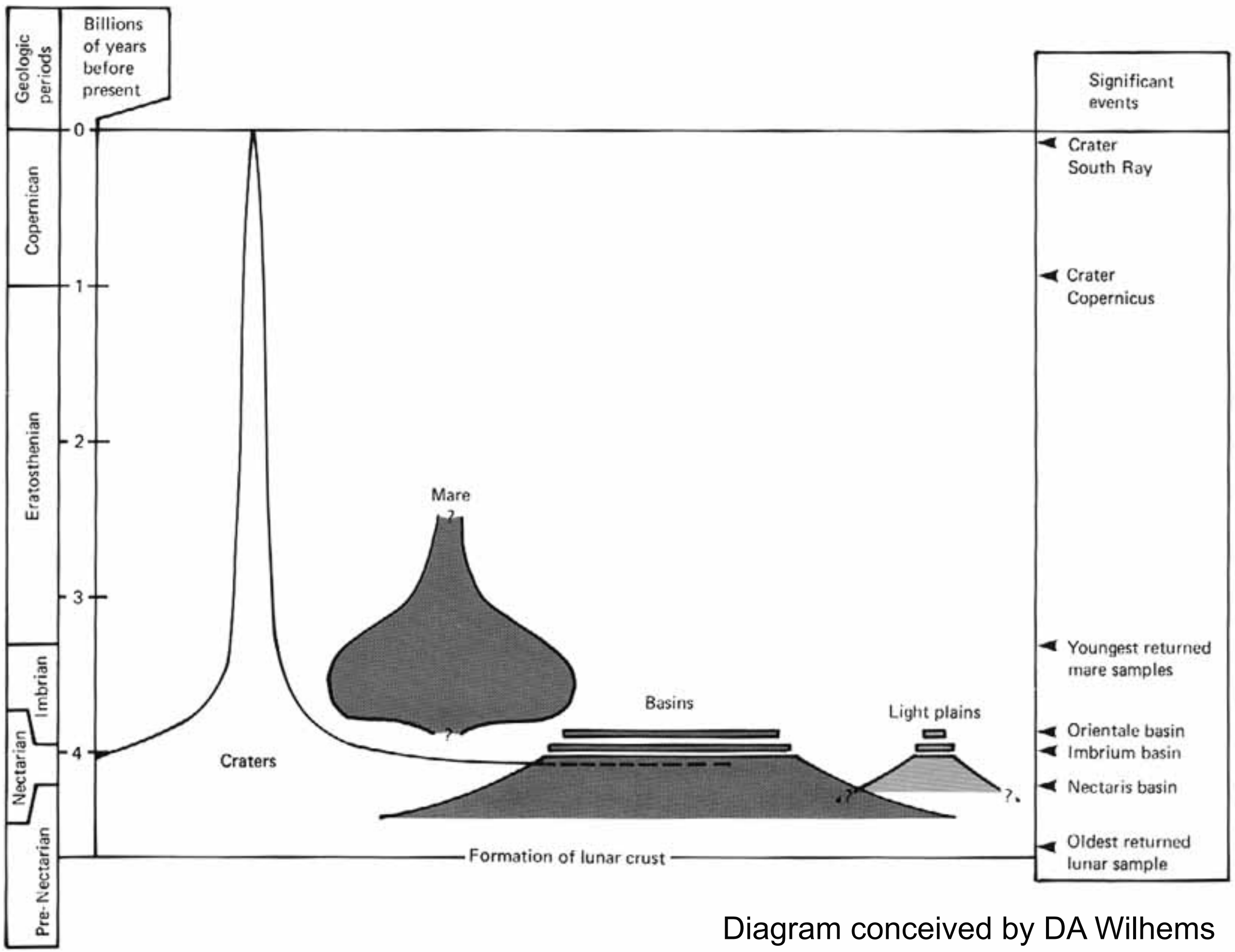
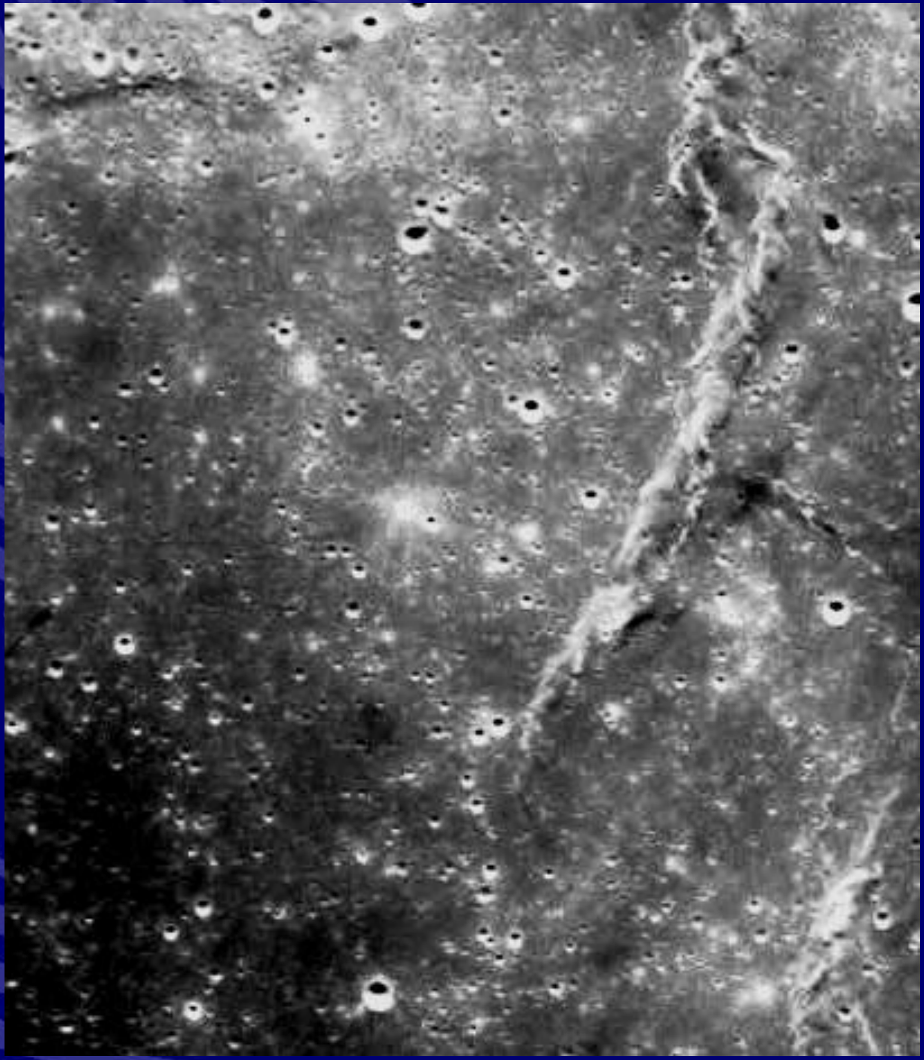


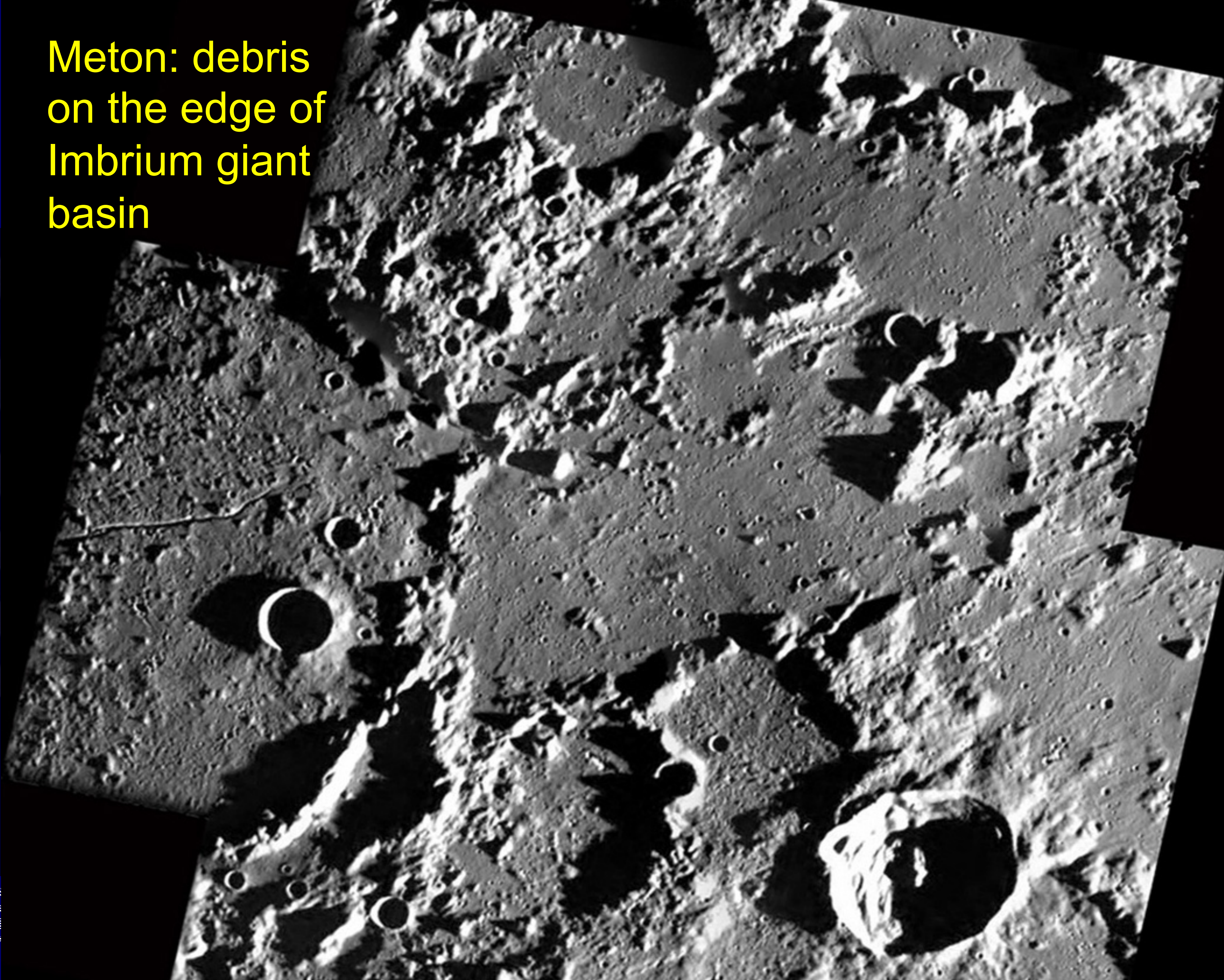
Diagram conceived by DA Wilhems

Serenitatis

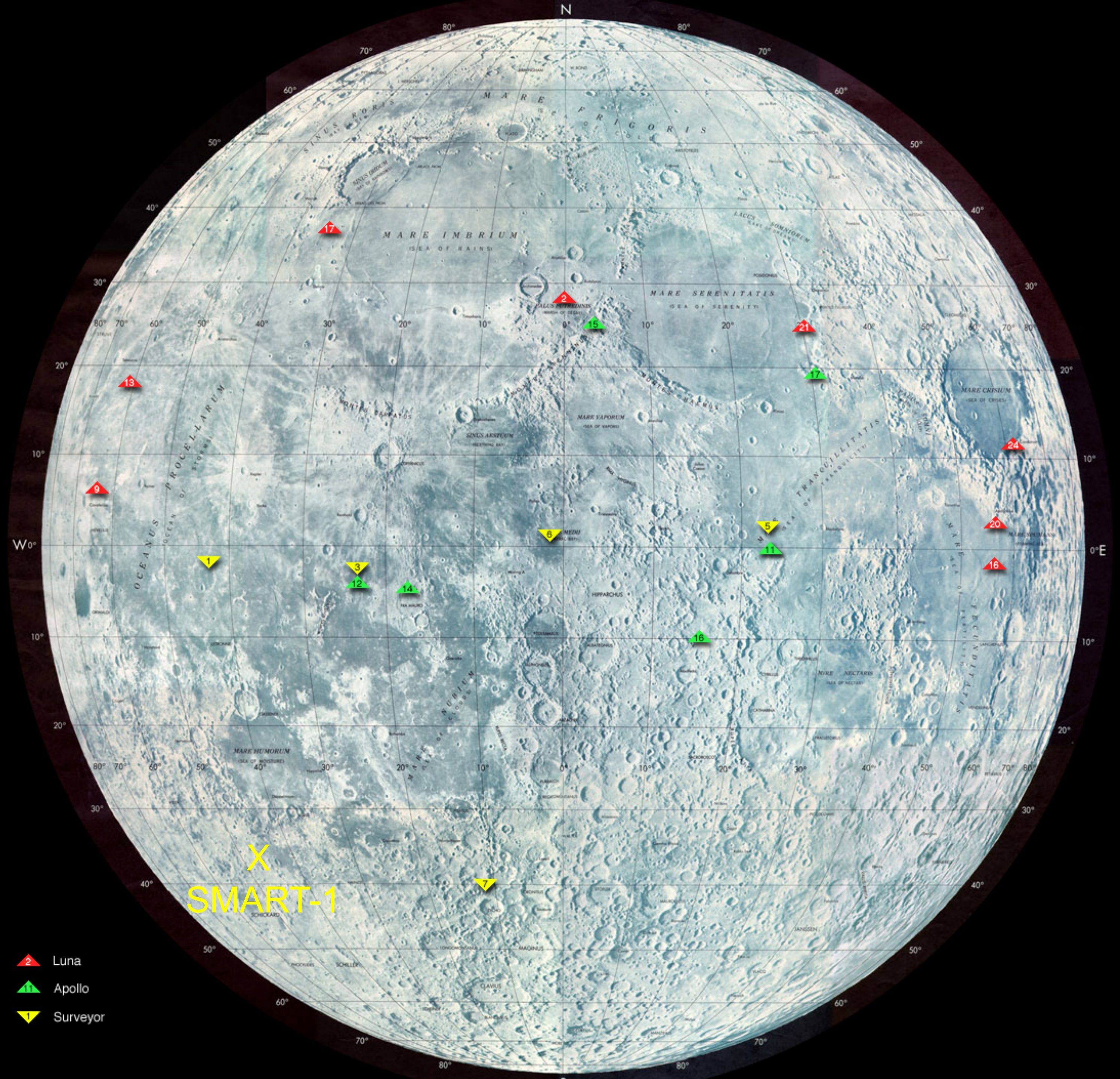
Crater counts and lunar chronology



Meton: debris on the edge of Imbrium giant basin

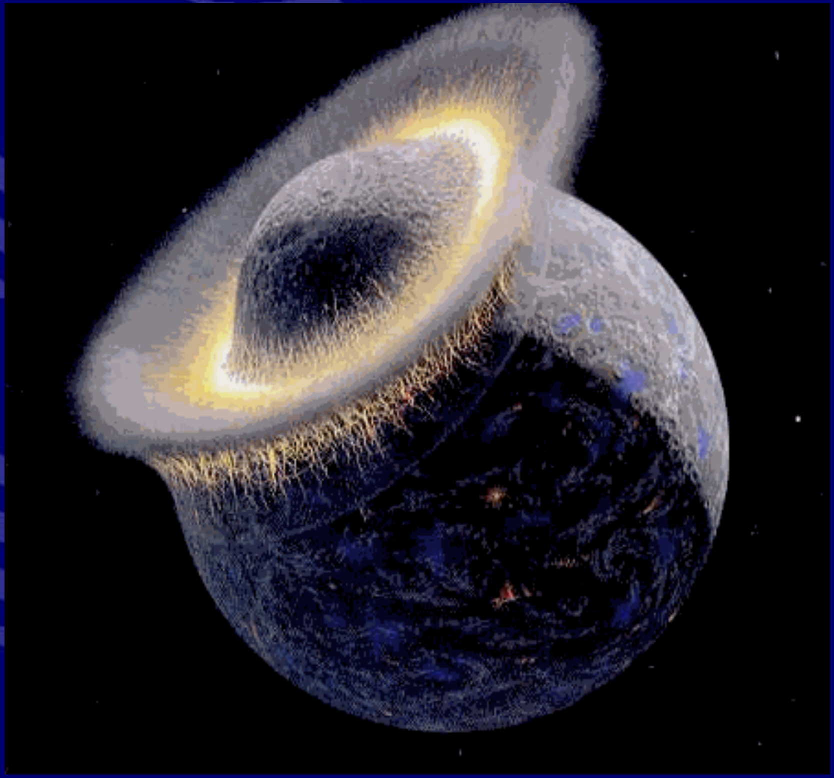


- Lunar landings

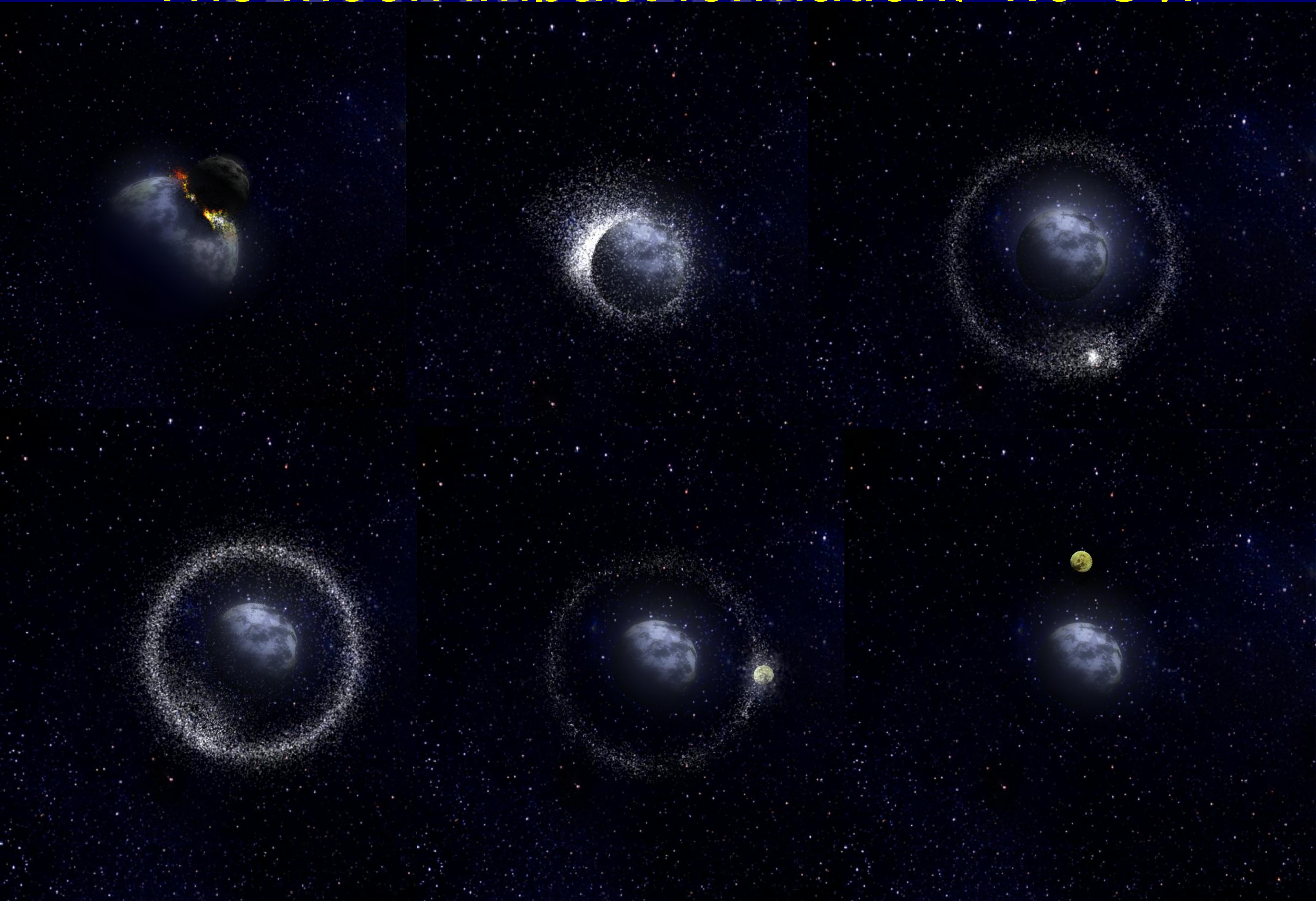


Unanswered questions about the Moon

- How did the Earth-Moon system form?
  - *Giant Impact? Origin of impactor? Volatiles?*
- How has the Moon evolved since?
  - *Magma ocean?*
- Necessary data
  - *Composition (Mg, Al…)*
  - *Age and isotopic composition*



The Moon impact formation. 4.5 Gyr



Science rationale for lunar sample return

Robotic Moon polar sample fetcher and return

no polar highlands samples yet, cometary and meteoritic record, organics/Extinct/extant life in regolith and polar ices, Planetary protection issues

Farside south pole Aitken basin sample return from mantle/lowercrust,

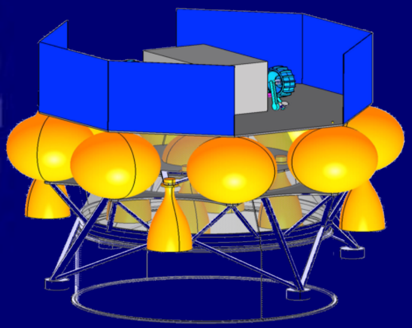
Sample return from youngest lava basalts in Procellarum

Global lunar sampling

Vertical lithology of craters central peaks

Early Earth Sample return (in cooperation with in-situ humans?)

- Search for Earth samples, Fossils of organics & ancient life from Early Earth (4 billion years ago)
- Validation of extreme organics and life detection technologies
- Expanding life beyond Earth



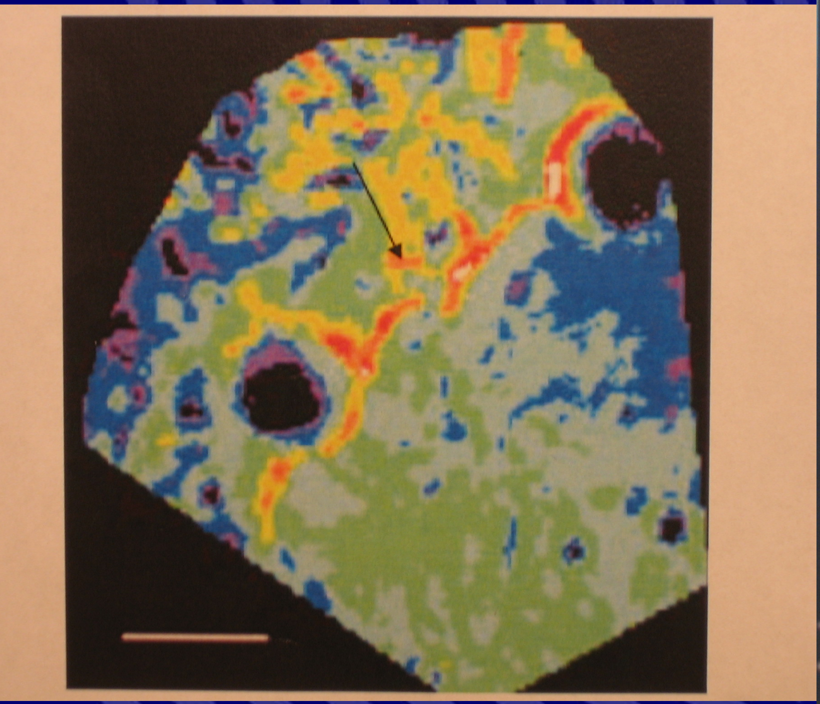
Technology demonstration

- Preparation for Mars sample return
- Lunar polar lander and rover fetcher
- Science opportunityTechnology demonstrator for lunar ascent vehicle and Earth reentry
- Preparation technology for human return vehicle
- ISRU demonstrator, He3 return demonstrator
- Life sciences and astrobiology lab sample return demonstrator,

Polar ice sample return

- 4 Gyr History of water, volatiles & organics delivery
- Permanent shadowed areas
- Core sample of ice
- Diversity of cometary and water rich asteroids
- Retrieve preserved samples
- Isotopic analysis, organics

North pole peaks of light

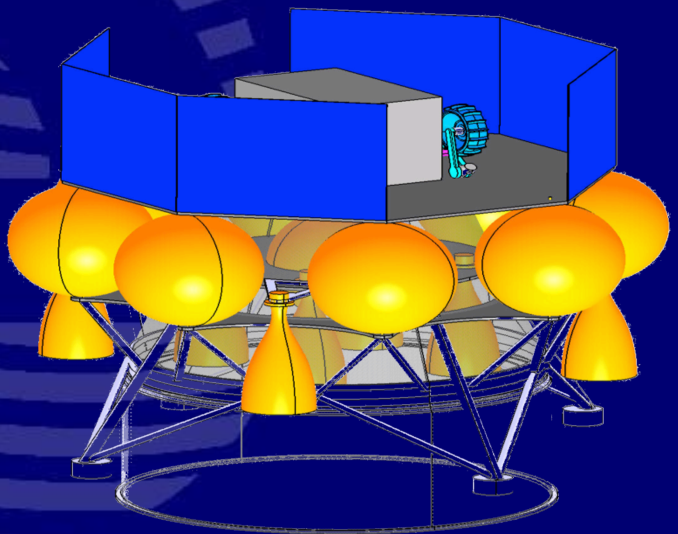


Summer average illumination
Clementine

Winter image
SMART-1

European Lunar Polar Lander LES3

1) Precise Landing on the Moon
2) Preparation of future exploration & sample fetcher
3) Geochemical study of polar regions
4) Ice Search/ characterisation
Cost 300 Meuro



- Lander station element
- Rover element
- Robotic challenge
- Orbiter and relay infrastructures

- Opportunities for Students, education, outreach, cultural, artistic experiments

- Part of global robotic village with RPLP2, Chang-E2, Selene 2, etc…

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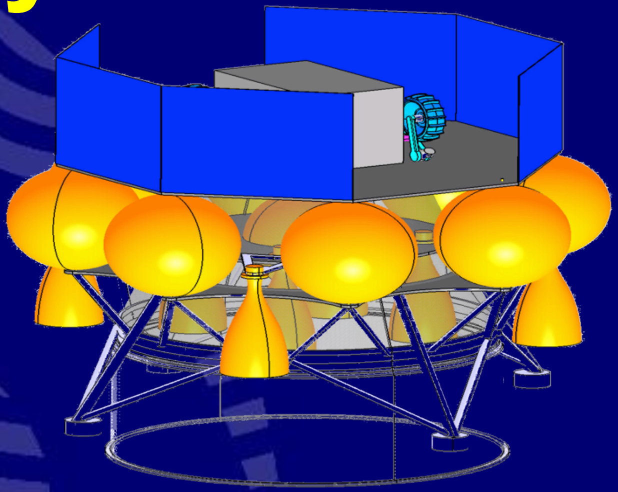
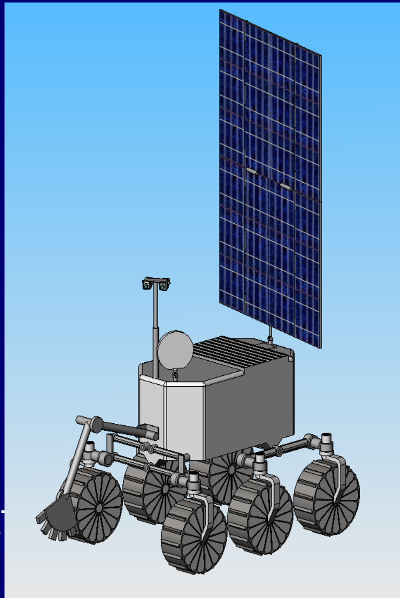
LES3 study



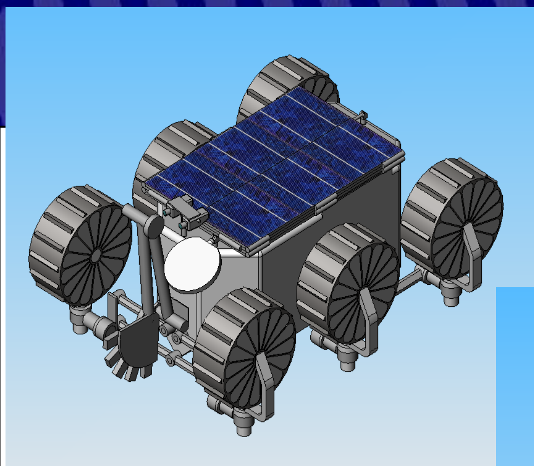
- Lander station element
  - Technology survival, operations
  - Geophysical network
  - Life sciences/environment
- Rover element
  - Close range mobility 50 m: nanorover
  - Regional mobility 1-10 km: Exomoon rover
  - Vertical mobility (penetrating sensors, moles, drill)

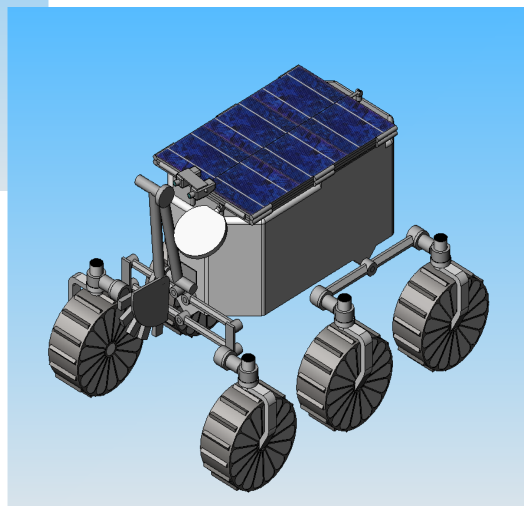
- Lunar Robotic Challenge
- Communication/navigation/survey infrastructure:
  - Small orbiter with HRSC camera and data relay
  - Exchange/support other international orbiters/ landers

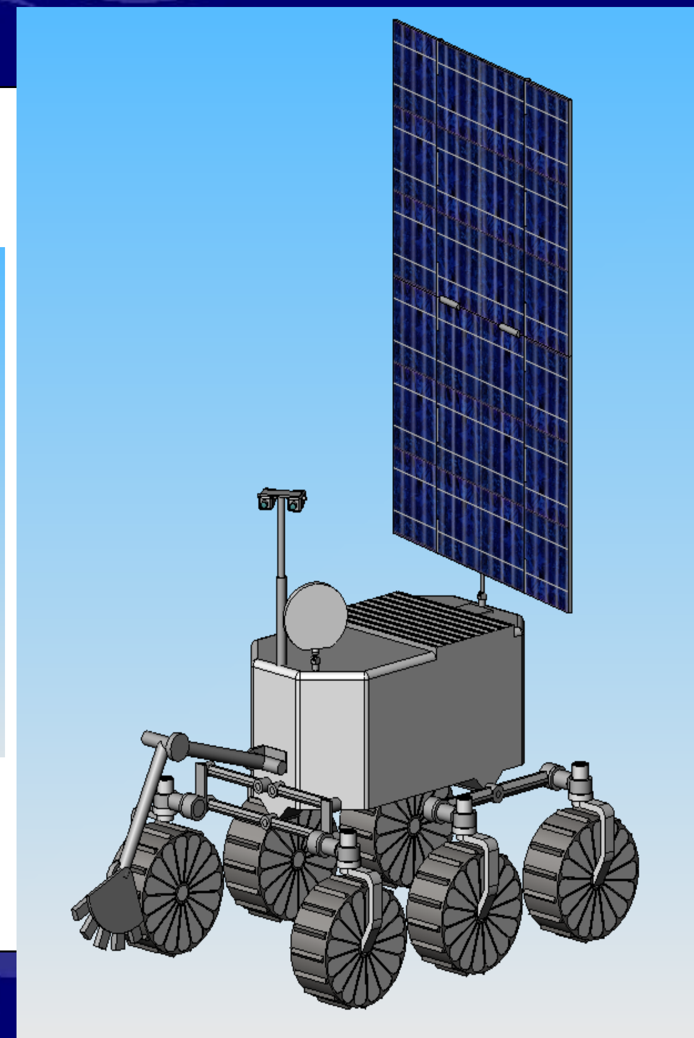
From SMART

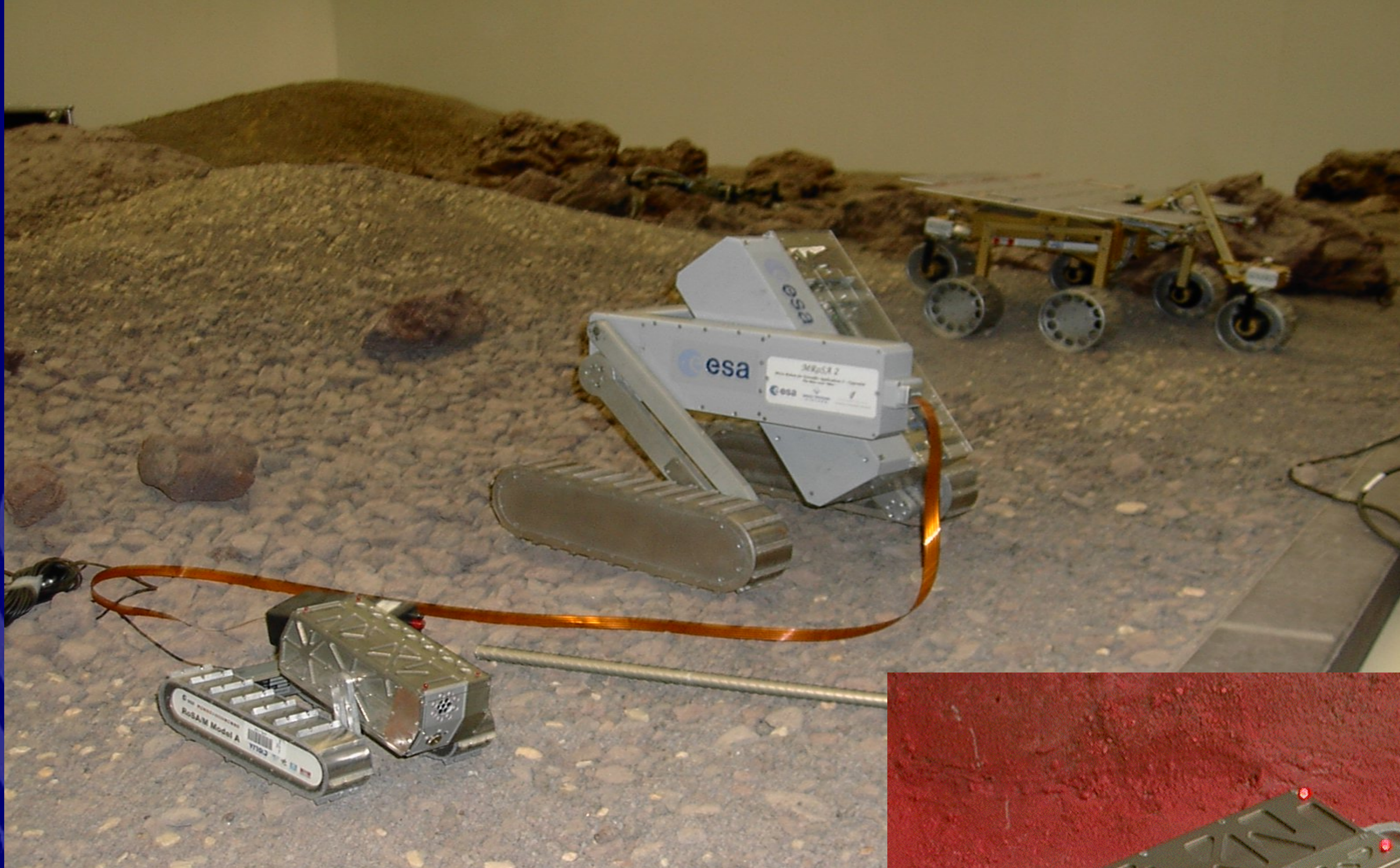


Conceptual design for lunar regional ExoMoon rover inherited from ExoMars



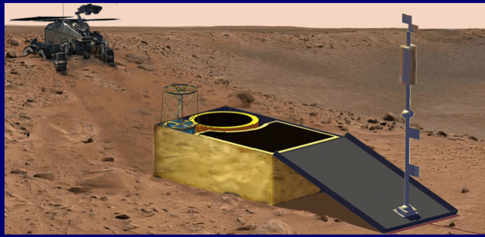




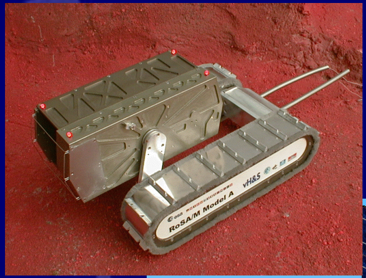


Tethered small rovers (4-10 kg)

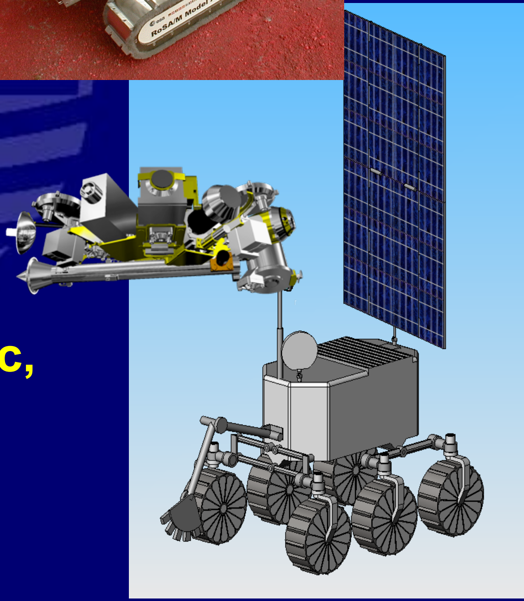
Instruments for Moon landers (100-180 kg):



- ELP European Lunar Geophysics package: 15-20 kg
  - Seismometer, Geodesy and laser , Heat flux, Magnetometer
- Lander instruments: 10 kg
  - Cameras: Descent, Pan Cam, Stereo, SRC
  - Local sample analysis (GCMS), permittivity
- Life science/environment experiments : 7 kg
  - Radiation/ environment/planetary protection studies
  - Melissa bacteria precursor, plants on the Moon



- Close proximity Rover: 5 kg
  - Neutron spectrometer, APX , Close up camera
  - Electromagnetic sounder, Ground penetrating radar
- ExoMoon Regional rover : 120 kg
  - Navigation and hazards avoidance, inspection cam,
  - Robotic arm (PAW like), drill and mole , Active seismic,
  - LIBS, Fluorescence, Thermal IR fluorescence
  - Dust lifting measurement device, QCM or cube piezo



- Lunar robotic challenge to access ice in dark: 15 kg . nanorover, harpoon, impactor,

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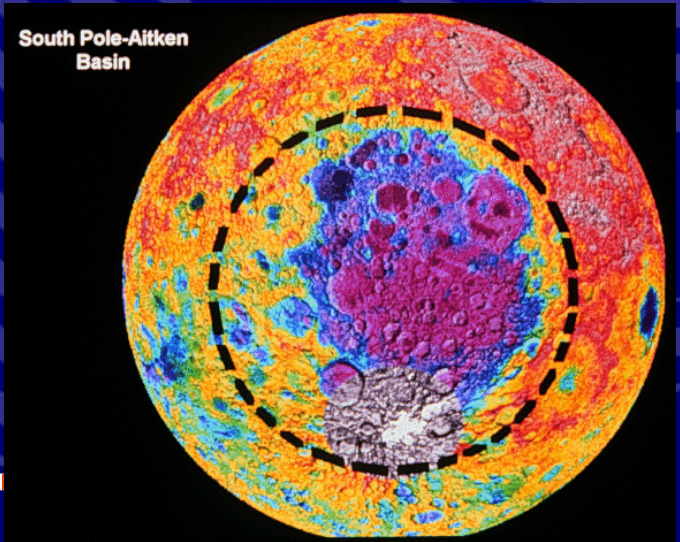
Sample return South Pole Aitken Basin

- window into the interior of the Moon and the past
- huge basin on the far side of the moon
- intensity of impacts there around 4 billion years ago
- to retrieve rock fragments
- two robotic landers and sample return
- Moonrise New Frontiers study heritage
- SMART-1 measurements of potential landing sites



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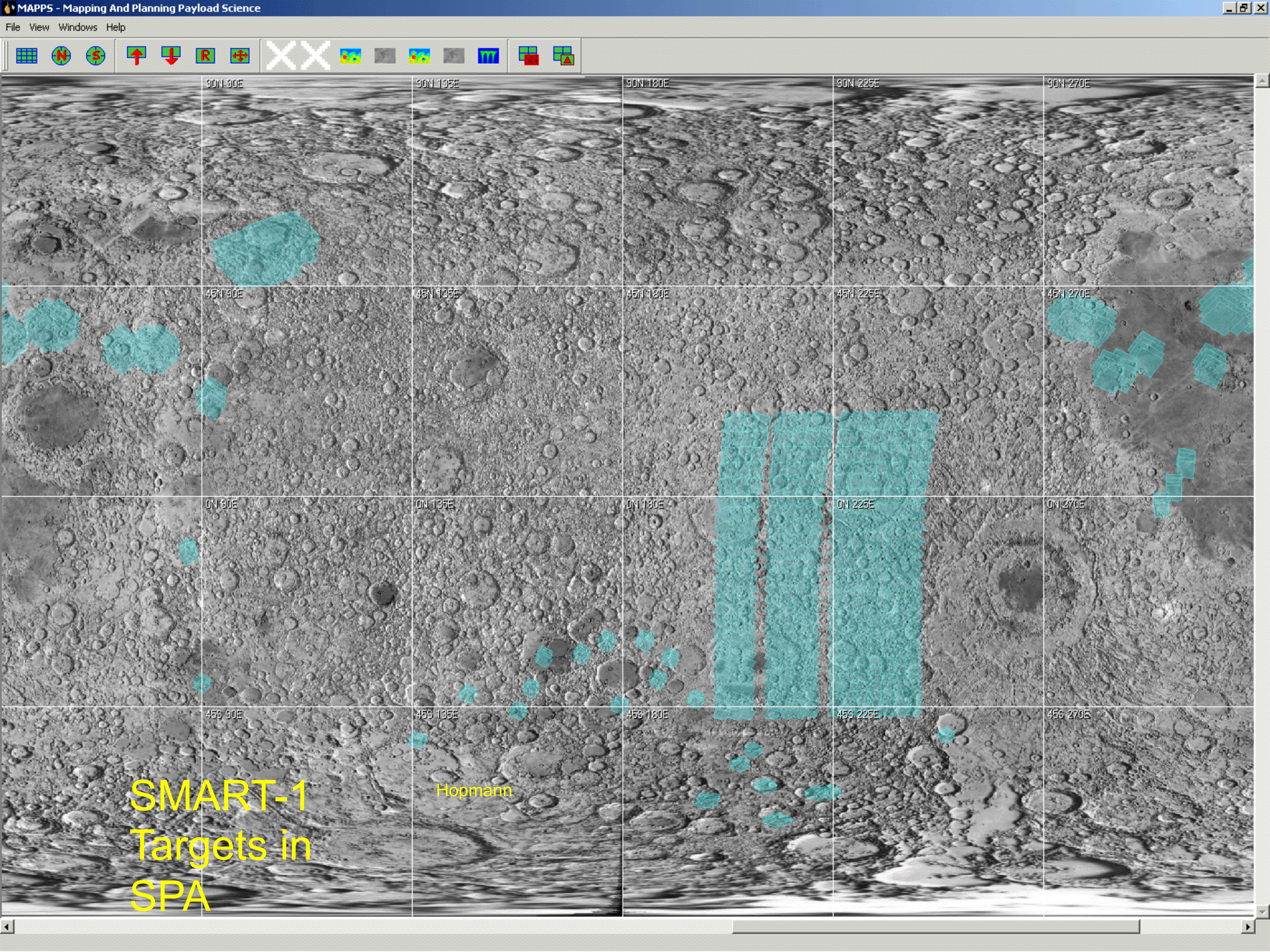
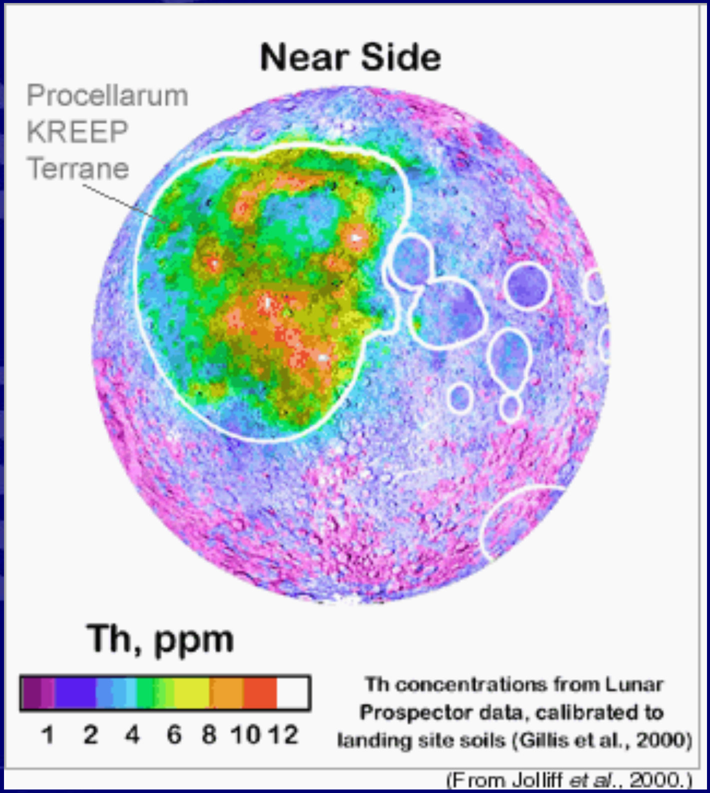


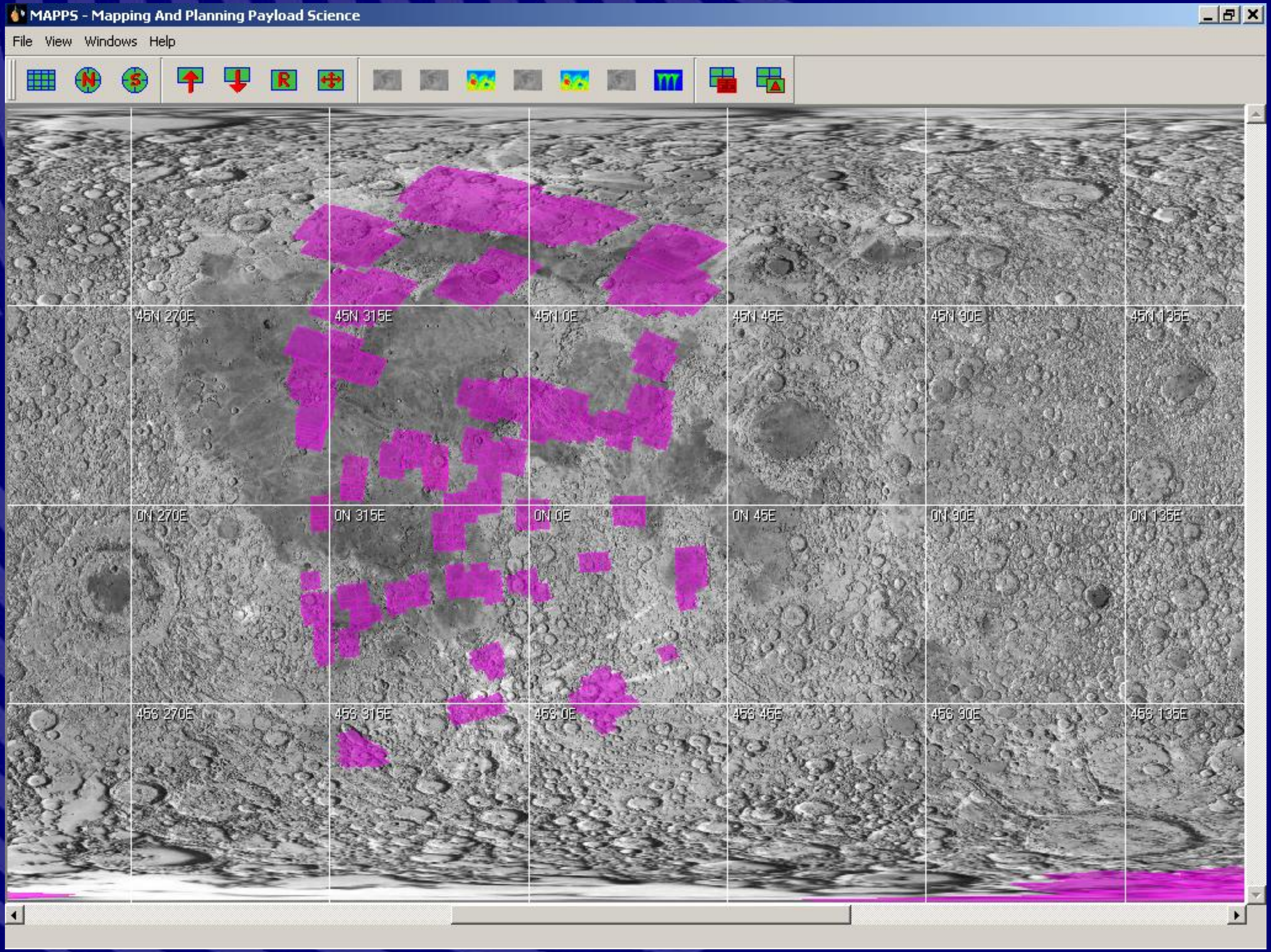
MAPPS - Mapping And Planning Payload Science
File View Windows Help
90N 90E
90N 135E
90N 180E
90N 225E
90N 270E
45N 90E
45N 135E
45N 180E
45N 225E
45N 270E
0N 90E
0N 135E
0N 180E
0N 225E
0N 270E
45S 90E
45S 135E
45S 180E
45S 225E
45S 270E
SMART-1 Targets in SPA
Hopmann

Oceanus Procellarum: Volcanism in KREEP-province

- Relatively low, but Noritic parts of the crust are not excavated
- Rich volcanic history → buoyancy not the only controlling mechanism
- KREEP-terrain rich in Th, U and K; heat from radio-active decay gives rise to magma due to thermal expansion

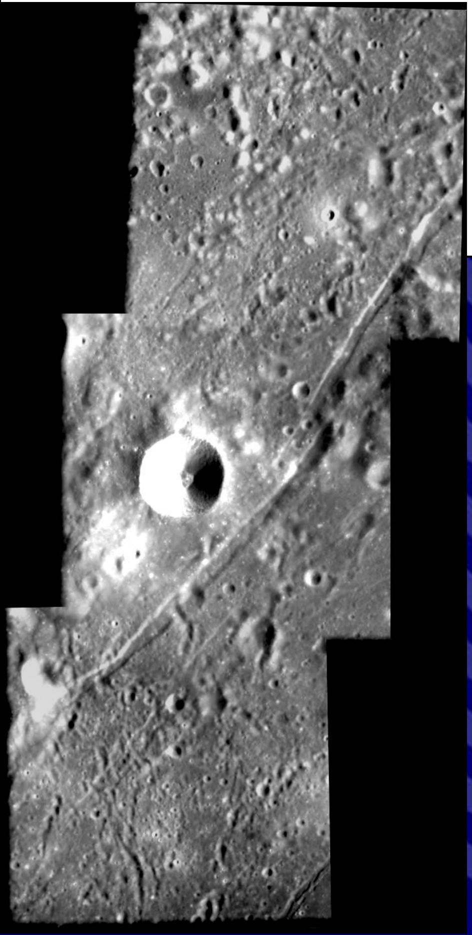


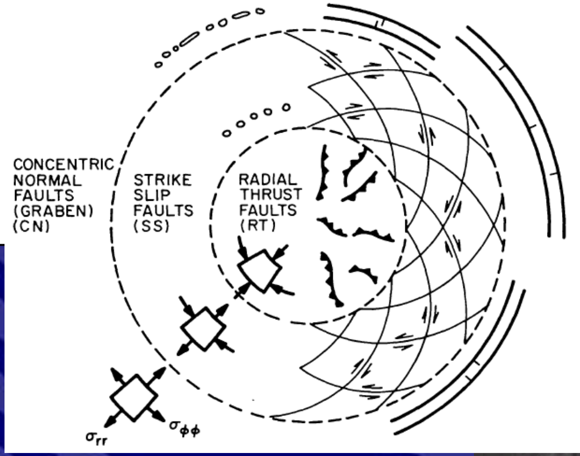
SMART-1 AMIE detailed targets: Procellarum and youngest basaltic flows

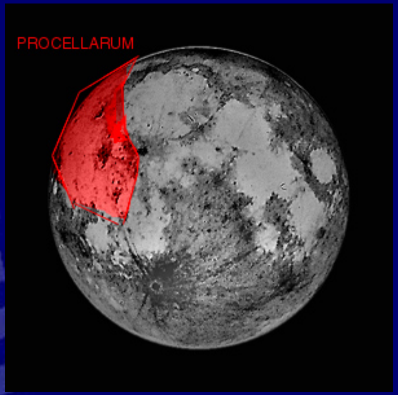


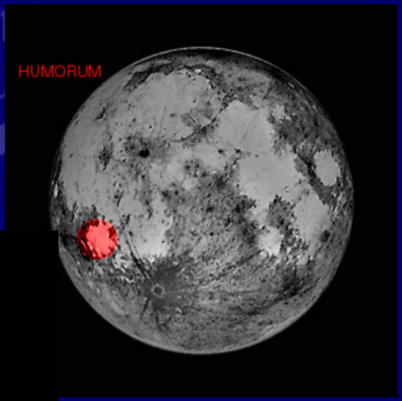
Coupling between impacts and volcanism

- Humorum: Multiringed impact basin
- Procellarum: Irregular basin
- Tectonics of mascon loading









Moon & Planetary Science

- Impact processes (from large basins to small SMART-1 impact)
- Cratering chronology
- Mineral vertical lithology variations from central peaks
- Volcanic processes and coupling
- Volcanic history & composition (Calcium in Crisium)
- Large impact basins (eg Imbrium, Humorum, Procellarum,)
- Constraints on Early and Late Heavy Bombardment
- South Pole Aitken Basin
- Moon Dichotomy
- Moon early evolution, Magma ocean and Crust Differentiation
- Surface composition Mg, Si, Al, Fe
- Constraints on Moon impact formation

- Preparing for future missions
  - Polar regions, volatiles, illumination and landers (in situ and samples)
  - Absolute chronology (samples)
  - Bulk composition and internal structure (seismometer)
  - Constraints on young Earth and solar system evolution

Sample Return Technology Synergies Moon- NEO-Phobos-asteroids-Mars

- Planetary entry (differences)
- Descent/ landing
- Rover sample fetcher (similar Moon/Mars)
- Robotics/sensors
- Ascent/return vehicle (local gravity, direct/RdV)
- Sample capsule/sealing (planetary protection differences)
- Earth reentry/shield (similar speeds)
- Sample curation
- Sample analysis isotopic, age, volatiles, organics

NEXT missions for Exploration Science & Technology

- Preparation for MSR and future exploration
- Call for ideas: 70 proposals (04/07), 32 on lunar missions
- Technological capabilities
  - Soft Precision Landing with Hazard Avoidance, RdV, Ascent, Reentry
- Mission Characteristics
- Lunar Lander Sample Return Precursor
- Scientific goals, investigations, instruments, sites
- Ongoing CDF concurrent design and industrial studies

NEXT & sample return: lunar ideas

- Lunar Robotic Sample Return
- Materially Self-sufficient Production for a Lunar Colony
- Integrated Lunar Demonstration Mission with Landing Science Package (Moon Farside Explorer)
- Lunar Sample Return
- A European Lunar Scientific and Robotic Lander Mission
- Lunar Dust Observatory
- Lunar Sample Return Entry and Aerocapture Demonstration Mission (LEAD)
- Lunar Sample Return Missions
- Direct Lunar Sample Return Mission
- Lunar Exploration Lander
- Surface Navigation Services
- Active Seismic Survey for Planetary Drilling
- Teleoperated Lunar Drilling – Exploiting Synergies with the Oil and Gas Exploration Sector
- ISRU Demonstration Facility on Lunar Surface
- MoonSailor
- Lunar Infrastructure For Exploration - Astronomy & Space Science Mission
- MoonTwin
- Exploration of Lunar Craters at the Moon's South Pole
- Landing of an Astrobiological Habitat at the Moon's South Pole
- Landing of an Astrobiological Habitat and a Micro-Rover at the Moon's South Pople
- Lunar Sample Return

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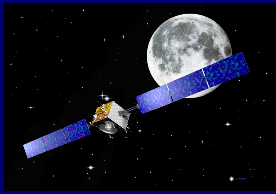
ILEWG9/ILC2007 Intl Lunar Conference

- 22-26 October 2007, Sorrento, Naples Bay, Italy, Co-hosted by ASI & ESA
- Co-chairs: S. Di Pippo (ASI), Wu Ji (China), M. Wargo (NASA), B.H.Foing (ILEWG/ESA)
- 1. Inauguration & Keynote speeches
- 2. Results from SMART-1, and latest reports from Chang'E 1 and Selene
- 3. Agencies activities and plans
- 4. Keynote speeches: Science, Technology, Human exploration
- 5. Status of Future Missions: Chandrayaan-1, LRO/ LCROSS, Future Orbiters
- 6. Science and Exploration of the Moon: Results, Open Questions and New Approaches
- 7. Technologies, Infrastructures, Resources for Future Robotic and Human exploration
- 8. Societal, legal, policy, economics
- 9 Next steps for Robotic Landers, Rovers and Outposts
- 10 International Prospects for utilization and human exploration.
- 11 Reports and recommendations from working groups
- 12 ICEUM9 recommendations and declaration
- 13 Young Lunar Explorers session
- Outreach/education for public and Youth
- 14 Posters & interactive sessions
- Geological field trip



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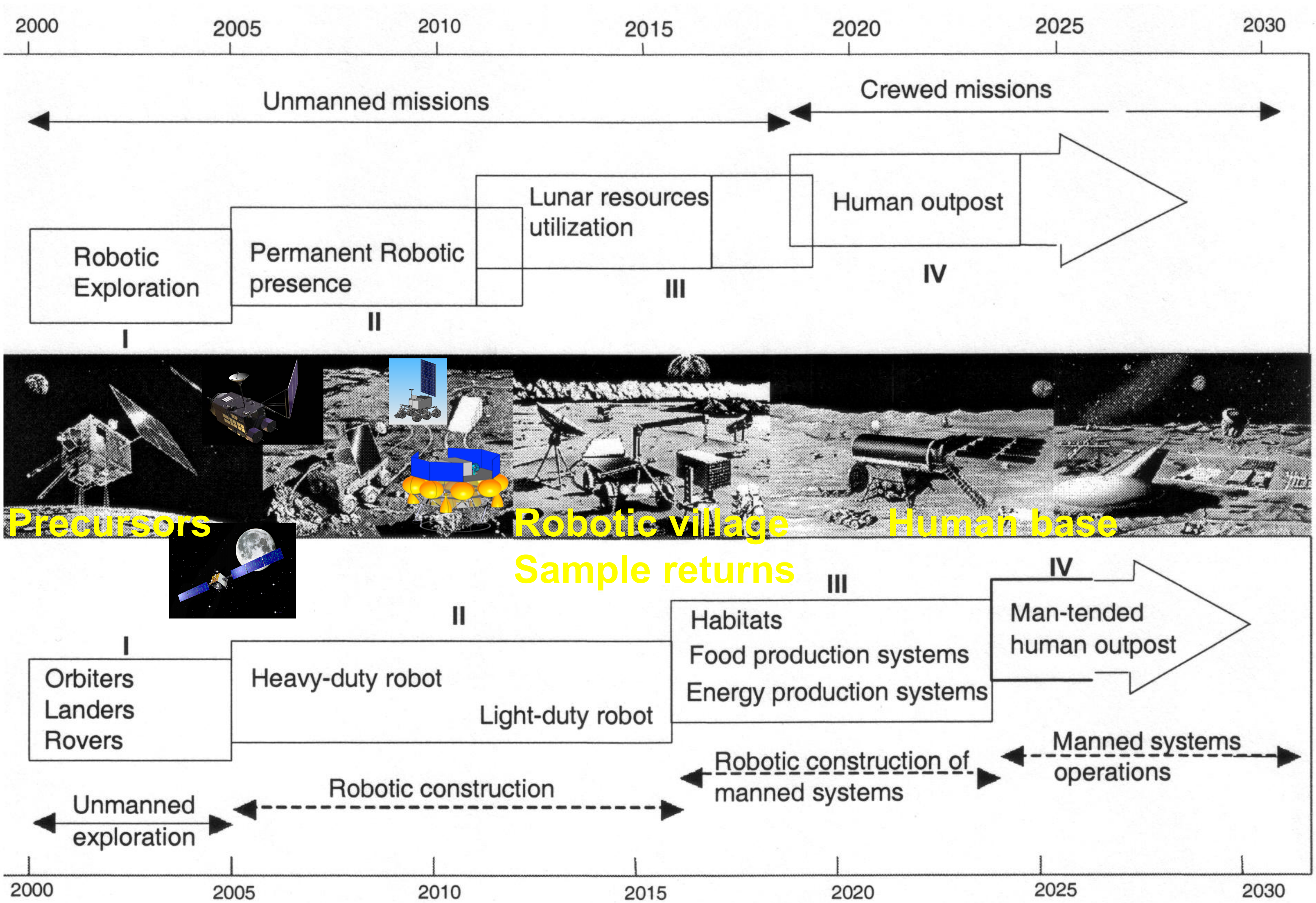
Roadmap: International Lunar Exploration Working Group (sci.esa.int/ilewg)



Lunar landers & sample returns

- What are the conditions for planetary formation?
  - Impact basins, bombardment chronology, isotopic dating
- What are the conditions for life?
  - Search for extraterrestrial ice and organics on the Moon, and chronology
  - Habitability of Moon: life sciences towards ecosystems, mini biospheres
  - Search for Early Earth samples
- How does the Solar System work?
  - Comparative planetology: (volcanics, tectonics, cratering, erosion)
  - Interior & subsurface: seismic network , geodetics
- Technology for future exploration/science missions:
  - entry airless bodies,
  - Descent and landing,
  - robotics ,
  - Instruments
  - Sample acquisition
  - Return and Earth reentry